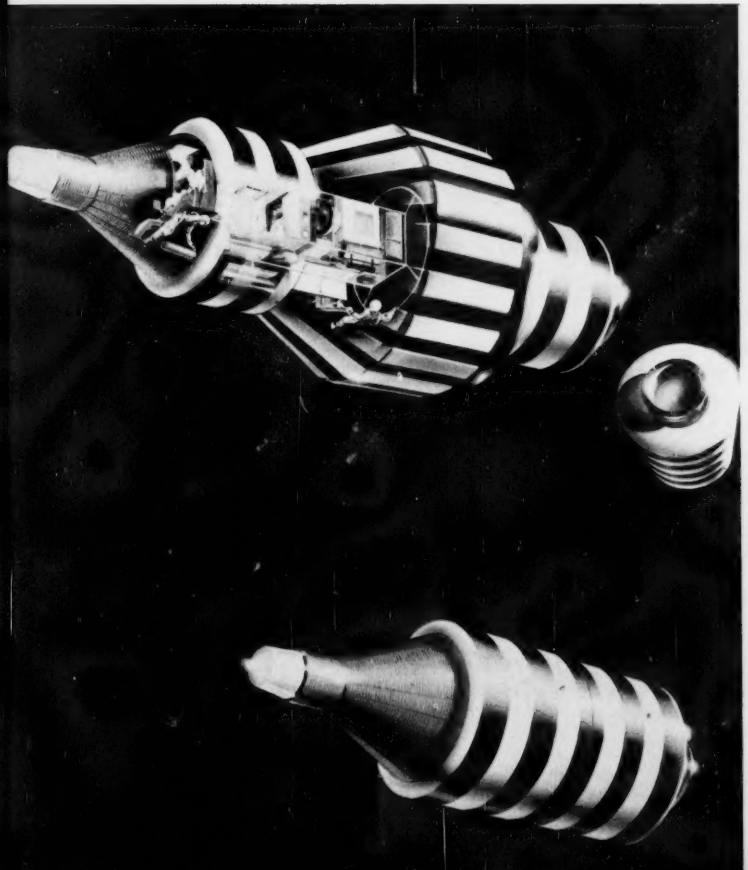
AUGUST 1961

the JOURNAL of ENVIRONMENTAL SCIENCES

OFFICIAL PUBLICATION OF THE INSTITUTE OF ENVIRONMENTAL SCIENCES

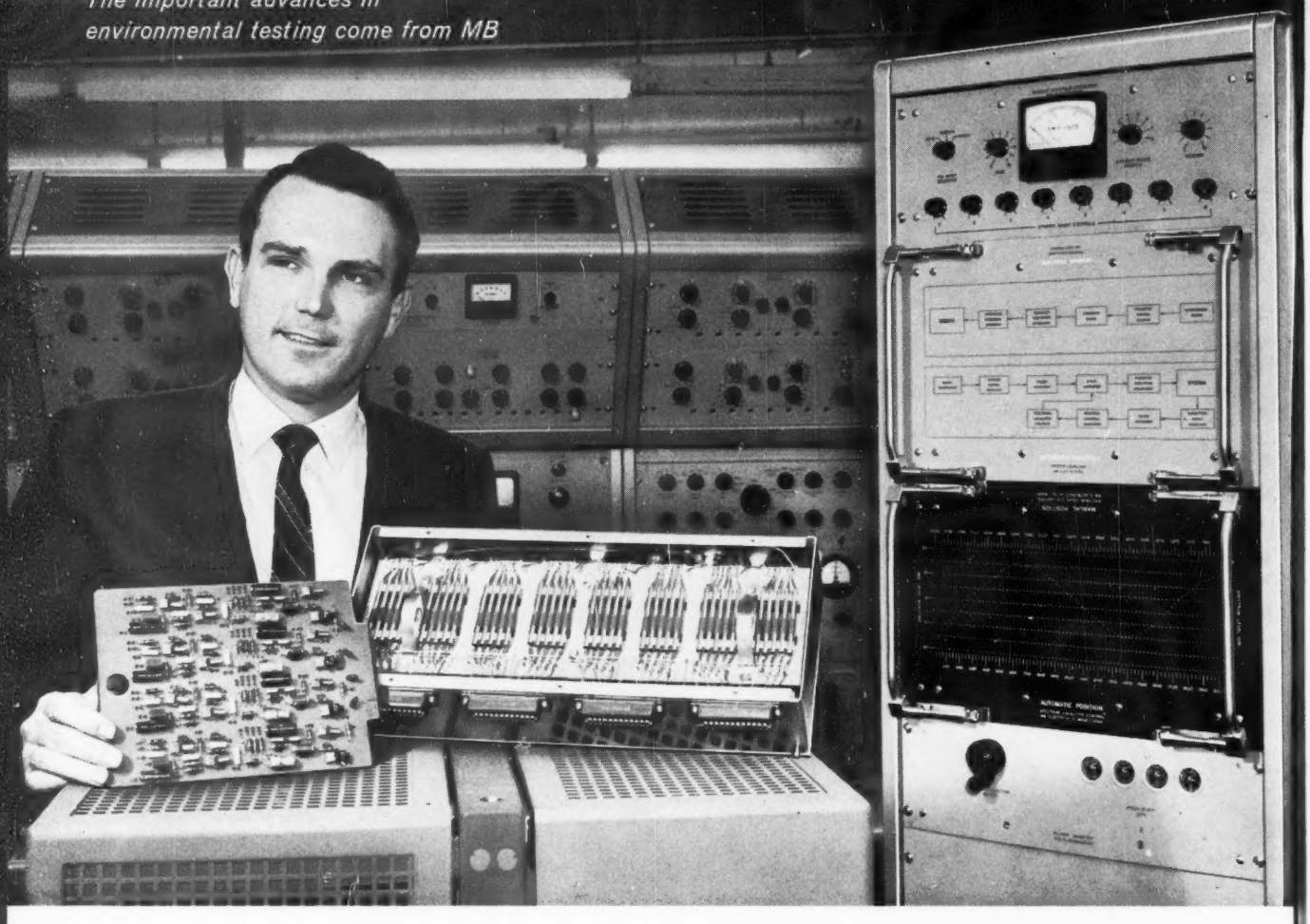


RANDOM – SINUSOIDAL VIBRATION STUDY

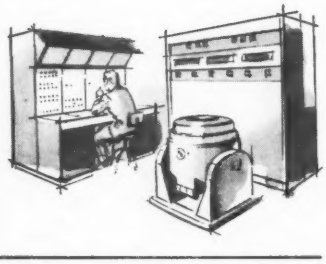
MARINE APPLICATIONS OF ENVIRONMENTAL ENGINEERING

FUTURE FACILITY
See Page 16

The important advances in environmental testing come from MB



Production random vibration now practical with MB completely automatic spectrum equalizer



Heart of the MB automatic equalization system is the multi-channel transistorized amplifier which provides amplitude control. The plug-in printed circuit assembly shown above contains four of these channels. Frequency control is provided by the 80-channel filter assembly in the compact metal box.

MB's completely automatic spectrum equalizer simplifies test procedure and makes production random vibration testing practical. It effects tremendous savings in test time and money for missile and aircraft manufacturers.

The reason: set-up time has been completely eliminated. Using solid state magnetostrictive filters with correct phase properties plus servo systems on each of eighty channels in the 15 to 2000 cps spectrum, vibration shaker systems can be completely equalized within 5 seconds.

Savings in time and labor over previous equalization methods can easily mean thousands of dollars per missile tested. Still another advantage is the greatly increased accuracy of accumulated test data. The spectrum is continuously monitored in narrow bandpass channels and compensation automatically made *during* test run.

Automatic spectrum equalization is another of MB's important and continuing contributions in the field of environmental testing.

MB ELECTRONICS

A DIVISION OF TEXTRON ELECTRONICS, INC., 1082 State Street, New Haven 11, Conn.

NATIONAL OFFICERS

President
ARTHUR B. BILLET
VICKERS INC.

Executive Vice President
DONALD J. FOX
FENWAL INC.

Fiscal Vice President
MARK CHRISTENSEN
AREOJET GENERAL CORP.

Local Chapter Vice President
GERHARD DOERING
COLUMBIA RESEARCH LABS.

Membership Vice President
HERBERT J. SAUNDERS
VAP-AIR DIVISION
VAPOR HEATING CORP.

Publications Vice President
JOHN D. CAMPBELL
PHILCO CORP.

Past President
WILLIAM L. VANDAL
FORD-AERONUTRONIC

Executive Secretary
HENRY F. SANDER

DIRECTORS

Boston
RALPH MARCUS
RAYTHEON COMPANY

Chicago
JOHN D. LOSSE
AC SPARK PLUG DIVISION, GMC

Los Angeles
BRUNO J. FORSHER
AEROSPACE CORP.

Michigan
OTTO ALTMAN
LEAR INCORPORATED

Mid-Atlantic
DAN GRADY
GENERAL ELECTRIC MSVD

New York
NORMAN PONGE
SPACE-TRONICS

Northern California
CURTIS R. SEYLER
AEROJET GENERAL CORP.

Northwest
JAMES C. STUART
BOEING COMPANY

Southern Ohio
JOHN L. CAHILL
LEDEX INC.

Southern Tier
RALPH G. MEZA

VOLUME 4 NUMBER 4

the JOURNAL of

ENVIRONMENTAL SCIENCES

For active Environmental Engineers and the executives throughout industry who are concerned with the advancement of Environmental Engineering by the Institute of Environmental Sciences.

Henry F. Sander MANAGING EDITOR
John D. Campbell TECHNICAL EDITOR
Ray W. Kopriva ART DIRECTOR

5 EDITORIAL

6 RANDOM - SINUSOIDAL VIBRATION STUDY

16 TEST LABORATORY OF FUTURE

17 MARINE APPLICATIONS OF ENVIRONMENTAL ENGINEERING

22 LOCAL CHAPTER NEWS

23 ENVIRONEWS

25 FELLOWS

28 NAVAL MEDICAL ENVIRONMENTAL ACTIVITIES

Mr. James C. Stuart, The Boeing Company, National Director of the Northwest Chapter has served as Assistant Technical Editor for the August 1961 issue of the *Journal of Environmental Sciences*.

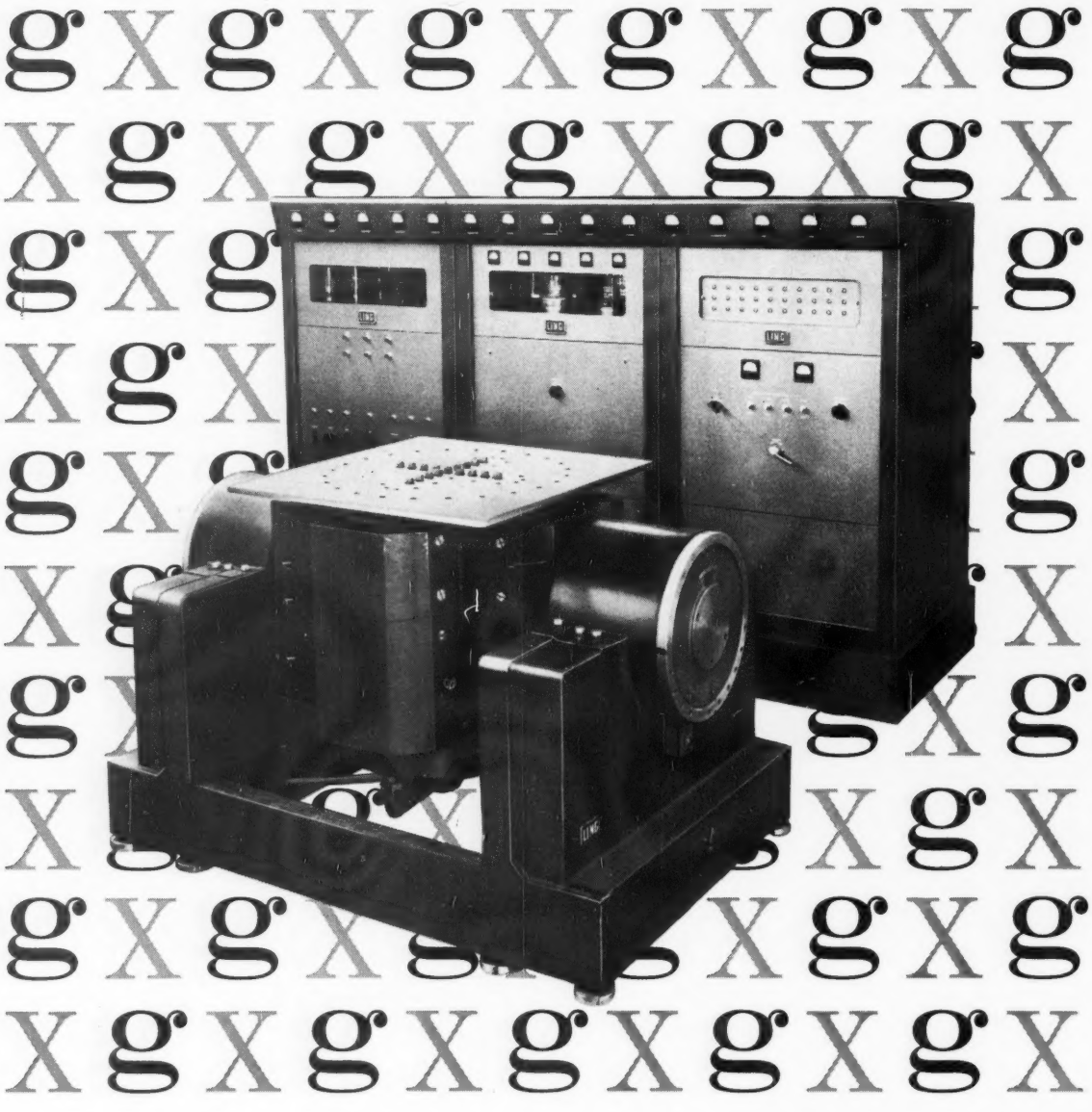
THE JOURNAL OF ENVIRONMENTAL SCIENCES is published bi-monthly by the Institute of Environmental Sciences at their National office, 34 S. Main St., Mt. Prospect, Ill., CLearbrook 5-1561. The JOURNAL is circulated free to all members of the INSTITUTE OF ENVIRONMENTAL SCIENCES, and is available to others by subscription. Subscription Rates: $5.00 per year (6 issues) in United States and Possessions and in Canada. Single copies: $1.00 per copy when available. Double prices for copies more than six months old. CHANGE OF ADDRESS: Allow 2 months. Please send old address as well as new.

Copyright 1961 by INSTITUTE OF ENVIRONMENTAL SCIENCES.

Send all correspondence regarding subscription, circulation, advertising and editorial material to the office of publication, The Institute of Environmental Sciences, P. O. Box 191, Mount Prospect, Illinois.

We cannot be responsible for unsolicited manuscripts.

For active Environmental Engineers and the executives throughout industry who are concerned with the advancement of Environmental Engineering by the Institute of Environmental Sciences.



ONLY LING'S NEW X-ARMATURE SHAKER TAKES 100 pound packages to 100 "g"... 250 pounds to 60 "g"

Ling brings you another important development in vibration testing—the revolutionary L-200 Shaker with the capability needed to test heavier packages at higher "g" levels than ever before. The L-200, with a force rating of 22,000 pounds, is designed on a new Ling concept. The unique "X" design armature develops uniform force on two rows of mounting studs which are set in an "X" pattern on the big table. An exceptionally low stray field—less than 3 gauss at table level—protects sensitive guidance packages. The armature weight is only 115 pounds. This, plus efficient coupling, lets you take a 100-pound package up to 100 "g" or a 250-pound package to 60 "g"—a performance no other shaker can match. The L-200's interior is completely sealed off to screen out all chips, dust or contaminants, and is designed to allow environmental test adaptability. For more details on the advantages of the L-200, write to Department JES-861 at the address below.

LING-TEMCO ELECTRONICS, INC.

LING ELECTRONICS DIVISION

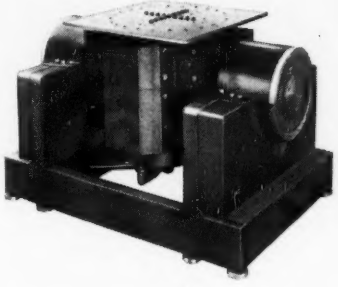
1515 SOUTH MANCHESTER, ANAHEIM, CALIFORNIA • PRospect 4-2900

LING ELECTRONICS

Ling engineers think big—and far ahead—to anticipate your needs in vibration testing equipment. The L-200 Shaker shown at the left is another example of sound Ling engineering at work—for this big shaker has every possible advance built in to improve testing accuracy and convenience. The L-200 takes you into the realm of high "g" testing with heavier-than-ever payloads.

Ling's newly designed hydrostatic bearings dampen cross axial movement of the shaker armature.

Gauss level during operation is exceptionally low, less than 3 gauss at table top. The control of the shaker angle is simple since rotation is hydraulically actuated! A visual 200° protractor has been built into each trunnion by Ling.



Check the capabilities of Ling's new L-200, 22,000-pound shaker:

VECTOR	MAXIMUM LOAD
20 "g"	985 lbs.
60 "g"	250 lbs.
100 "g"	100 lbs.

Whatever your needs in high power electronics—vibration testing, acoustics or sonar—you'll find you can rely on Ling for the soundest design, the most advanced engineering.

LING-TEMCO ELECTRONICS, INC.
LING ELECTRONICS DIVISION
HIGH POWER ELECTRONICS FOR
VIBRATION TESTING • ACOUSTICS • SONAR

EDITORIAL

Definitions and nomenclature are essential to clear explanations. In today's environmental testing, terms such as hyperenvironment, high vacuum, low temperature, etc., all require definition to be meaningful. There are other terms which are self-explanatory and usually do not require further definition.

It is quite disturbing and confusing to find the self-explanatory and accepted terms of "natural environment" and "induced environment" defined erroneously as a "*matter of convenience*". This is like saying that black is white and white is black.

The monthly periodical *Environmental Effects on Materials and Equipment Abstracts* published by the Prevention of Deterioration Center has taken the liberty of establishing new arbitrary definitions for "natural" and "induced". The preface of this periodical defines as some of the "induced environments such things as vacuum, gravity, electromagnetic radiation, meteoritic dust, auroras, and coronas". To justify their unique definition the preface continues:

> It is apparent that the choice of words to classify the newly important environment—induced, hyper, operational or space-associated—is somewhat confusing and inadequate. It is hoped that in time a more satisfactory designation will be found. Many of the newly recognized environmental factors are, for example, quite "natural". For the purpose of this preface, however, the terms *natural* and *induced* are being used as a matter of convenience".

Accepted definitions are:

a. Natural environment—one that exists in nature and is not dependent upon the presence of an artificial object.

b. Induced environment—one that exists or is created by virtue of the presence, operation, or motion of an artificial object.

Such arbitrary definitions as used in the monthly abstract bulletin cannot be condoned. It is hoped that the "convenience" for the writer will be corrected to prevent confusion for many.

BETHLEHEM EXPANDS

ENVIRONMENTAL ENGINEERING DIV.

Now offers the industry's widest range of environmental test equipment for every military, industrial and research requirement.

ThermaLine
SERIES 400

Standard Capabilities:
TEMP: −200°F. to +400°F.
ALT: 100,000 ft. and up
HUM: 5% to 98% RH

ThermaLmaster

Available in following standard sizes:

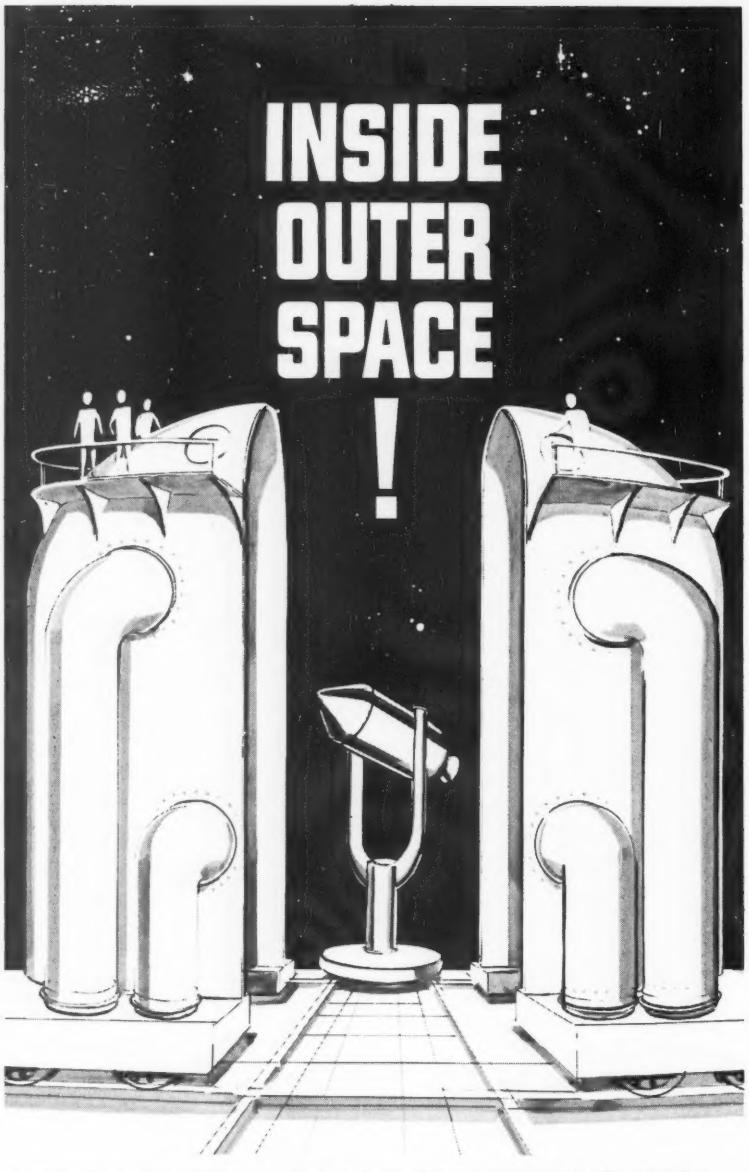
Cu. Ft.	H.	W.	D.
4.6	20"	20"	20"
12	36"	24"	24"
36	48"	36"	36"
64	48"	48"	48"

Write for Bethlehem's complete environmental product catalog

BETHLEHEM CORPORATION
225 W. SECOND ST., BETHLEHEM, PA.

ENVIRONMENTAL ENGINEERING DIV.

OTHER **BETHLEHEM** PRODUCTS: CHEMICAL PROCESS EQUIPMENT, CEMENT MILL MACHINERY, SPECIAL MACHINERY, AUTOMATIC HEATING EQUIPMENT; FOUNDRY, FABRICATION AND MACHINE SHOP SERVICES.



Or shall we say, outer space goes indoors. However you put it, the meaning is the same: Tenney has brought the exotic hyper-environments of outer space down to earth — and put them into Space Simulators engineered to create, measure and evaluate the effects of extreme spacial altitudes, solar radiation, blistering heat, cryogenic cold and orbital motion. All to assure the safe and certain progress of space exploration.

Tenney's space simulation engineers, with more combined experience than any other company, can help you with your particular project. Write to Mr. Frank Gardner for further details.

Tenney ENGINEERING, INC. Aerospace Division
1090 SPRINGFIELD ROAD • UNION, NEW JERSEY
OLDEST AND LARGEST MANUFACTURER OF ENVIRONMENTAL TEST EQUIPMENT

Foreword

This technical study was initiated by the Engineering Test Division of the Flight and Engineering Test Group, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, under Air Force Contract No. AF 33 (616)-7142, Task No. 13002, on Project No. 1309, "Flight Vehicle Environmental Investigations." Mr. Neal Granick served as original contract monitor, and was later replaced by Mr. David Earls.

The research work upon which this report is based was accomplished by Collins Radio Company, Cedar Rapids, Iowa. The author, Dr. J. Earl Foster, Head of Group B-4-A, Collins Radio Company, was project engineer in charge of basic research and development work. Mr. Maarten Vet, Group B-4-A, Collins Radio Company, assisted the author in engineering research and in preparation of this report. Acknowledgment is made of the assistance provided by the personnel of the Environmental Test Laboratories and Wave Analysis Section, Collins Radio Company.

Research started on 28 July 1960 and was completed on 31 January 1961.

Introduction

In recent years, an appreciable amount of attention has been focused on the problem of simulation and analysis of random signals. Good examples of random signals, or random noise, are the acoustic noise generated by the turbulent exhaust gases of an aircraft jet engine and the noise emitted by the rocket engine of a missile. The rapidly

RANDOM-SINUSOIDAL VIBRATION CORRELATION STUDY

By J. EARL FOSTER
Collins Radio Company

increasing importance of this environmental condition has introduced the problem of analyzing the effect of the random environment on the structures and control systems of these weapons systems.

The question has been posed, "What failures are produced with random vibration that cannot be produced with sinusoids?"[1] With the rapid advance of aircraft and missile technology, the answer to this question has become of extreme importance. As far as can be determined to date, the basis of correlation between random and sinusoidal excitation has been damage due to fatigue. For simple, mechanical structures, this method of correlation may be sufficient, but for complex electromechanical equipments, fatigue failure is not necessarily a valid basis for comparison. Very often an equipment of this nature may structurally withstand a high excitation level, but will be rendered useless at a lower level due to high degradation of its electrical output. For intricate electromechanical equipment, such as that used in the field of avionics, a more reasonable criterion of correlation would appear to be degradation of the electrical output signal. In the investigation related in this technical report, Collins used electrical degradation as a criterion to determine if random-sinusoidal correlation could be obtained.

Expected Results

The experimentation carried out by Collins was of an applied research nature. A survey of literature in the field will yield analytical discussions on the theory of random vibrations, so it is considered beyond the scope of this report to present theoretical results. A detailed discussion will be presented of experimental procedures and results obtained.

The response of an elastic system to a slow-cycle, sinusoidal excitation will plot as a ragged curve with numerous peaks and valleys as functions of frequency. The response to random excitation, if analyzed over a narrow bandwidth, will yield the same type of results. Wide-band random noise, on the other hand, will show a nearly constant rms noise level that cannot be compared to sinusoidal results.

A typical plot of expected results is shown in figure 1.

This figure shows the electrical noise response generated by a particular level of sinusoidal and random excitation. The random response is assumed to have been analyzed over a narrow bandwidth and plotted as a function of the center frequency of the filter.

In order to make use of the data obtained by test results and show whether or not correlation exists between the two means of excitation, it is necessary to cross plot the data at particular frequencies. For example, if activity or resonance occurs at a particular frequency for an equipment, a curve would be plotted showing various values of noise signal produced for

Reference

[1] "Status Report on Random Vibration Simulation," Neal Granick, WADC Technical Note 58-274, ASTIA Document No. AD203125, November 1958.

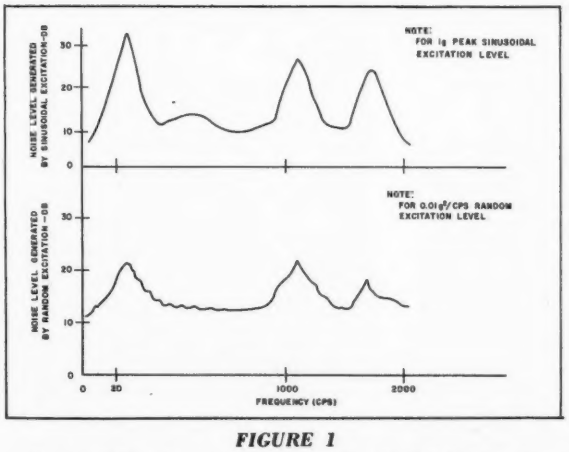


FIGURE 1
Expected Test Program Results—Electrical Noise Results for Particular Levels of Sine and Random Vibration

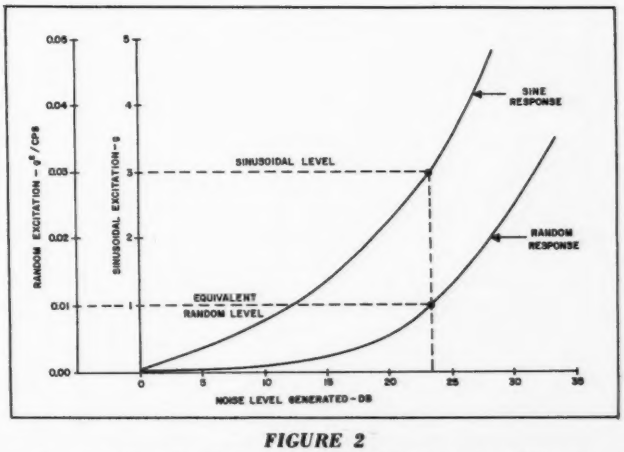


FIGURE 2
Expected Test Result Curves from which Equivalent Vibration Excitations can be Obtained

About The Author

Dr. Foster received his Bachelor of Science degree from the U. S. Merchant Marine Academy in June 1950. Following two years of active duty with the U. S. Navy, he enrolled at the State University of Iowa and received the MSME degree in August 1955. He joined Collins Radio Company in January 1957, and continued graduate school at SUI, receiving his Ph.D. in Mechanical Engineering in August 1958.

At the present time Dr. Foster is in charge of a thermal, vibration and shock group at Collins Radio Company and is also a lecturer in the Mechanical Engineering Department at State University of Iowa. In the fall he will join the University of Wyoming as an Associate Professor in the Mechanical Engineering Department.

various excitation levels. By noting the random excitation level necessary to produce a certain response noise level, and comparing this with the sinusoidal excitation necessary to produce the same noise level, an effective correlation is obtained. Such an expected curve is shown in figure 2.

From these curves, at the particular noise level chosen, equivalence can be obtained in the form of a ratio between sinusoidal and random excitation levels. Should the ratio remain a constant value, as determined from various excitation levels on equipments tested, then the deduction would be that a correlation does exist. Even if the ratio of the two excitations varied in some linear fashion with frequency, a correlation still could be evaluated. If, however, the ratio did not remain constant but varied with the type of equipment, with frequency, or with other variables, the deduction would be that no correlation exists and random vibration cannot be simulated effectively by sinusoidal excitation.

Equipment Tested

1. RADIO SET AN/ARC-70 OF COMMUNICATION - IDENTIFICATION - NAVIGATION SUBSYSTEM AN/ASQ-37.

The AN/ARC-70 provides two-way amplitude modulation (AM) radiotelephone communication between aircraft in flight, aircraft and shore, and aircraft and ship. The radio set is capable of transmitting and receiving on any one of 1750 frequency channels spaced at 100-kc intervals, in the band of 225.0 mc to 399.9 mc.

The unit consists of a main chassis, cover, and eleven plug-in subassemblies (modules). The main chassis is divided into two sections, the mounting base and main casting; the modules are attached to the mounting base by captive screws. All electrical connections between the modules and the main chassis are made through multiconnection plugs on each module to jacks mounted on the main chassis.

When this unit is subjected to vibration excitation, electrical noise is generated internally by the action of tube elements, mechanical clearances, motion of sensitive tuning elements, relay chatter, etc. The generated noise modulates the carrier frequency, is detected in the audio section, and has the effect of reducing the communication range of the radio.

In performing the test, an unmodulated signal of 10,000 microvolts was supplied to the receiver antenna input. A signal of large intensity was used to reduce the residual noise output of the receiver to a very low level. The audio output of the unit was measured, properly attenuated, and recorded on magnetic tape. Any modulation of the carrier caused by vibration excitation of internal parts appears as an increase in the audio output. This increase of output can be measured above the reference level established with no vibration to determine the electrical degradation of the signal.

2. APPROACH HORIZON INDICATOR 329B-4A OF INTEGRATED FLIGHT SYSTEM FD-105.

The approach horizon indicator is a panel-mounted instrument that presents to the pilot a pictorial display of the pitch and bank attitude of the aircraft, the position of the aircraft with respect to a glide slope beam, and computed lateral guidance information. The instrument also contains warning flags which appear if a malfunction occurs in the attitude display system, the glide slope signal system, the localizer, VOR signal system, or the steering pointer signal system. This instrument contains six meters, a steering pointer, glide slope indicator, localizer flag, glide slope flag, steering flag, and gyro flag.

The 329B-4A consists of two motor-driven servo units and the six 1000-ohm meter movements enclosed in a nonpressurized, dustproof case. All electrical connections to the instrument are made through dual connectors at the rear.

The test items of interest, for this particular unit, were the six meters. A sinusoidal vibration excites the meter movements of the instrument individually at their resonant frequencies. This vibration affects the individual bearing supports, bearing clearances, etc., making this indicator an ideal item of study.

To examine the response of the unit to vibration, the instrument was tested without electrical power applied to the meter movements. Instead, the electrical circuits of each meter were terminated properly so that the movement of the display needle or flag caused a voltage to be generated in the meter circuit. The circuit was monitored, and after proper amplification, the individual signal voltages were recorded on magnetic tape.

Laboratory Facilities and Equipment

For the purpose of performing the testing described herein, three vibration tables were used. All three tables were

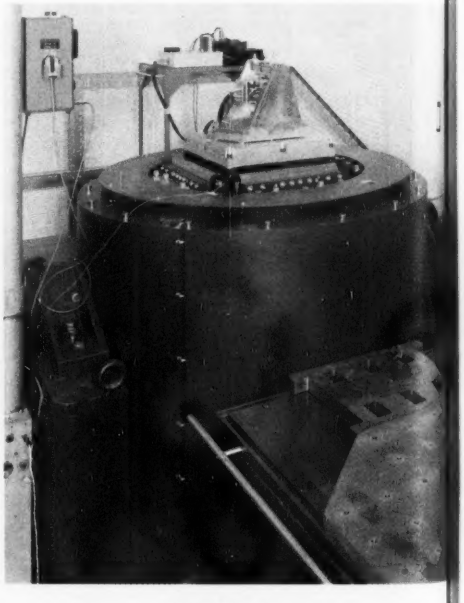


FIGURE 3

Collins 10,000-Lb. Vibration Shake Table

utilized to perform preliminary sinusoidal excitation studies, whereas all the final testing was performed on a particular shaker.

The final testing of equipments while being subjected to random and sinusoidal excitation was performed on a Model 182 shake table manufactured by the Ling-Calidyne company of Los Angeles, California. The shaker capacity is 10,000 force pounds with a frequency range of 5 to 2000 cps. The unit is equipped with a hydraulic or "slider" type horizontal table which consists of a large, ground, steel plate imbedded in a concrete foundation. A thin film of oil is spread over the ground surface of the steel plate, and a two-inch thick magnesium plate, which is bolted to the shake table, slides on the oil film. A photograph of the unit is shown in figure 3

A second vibration table is a Model C25H machine, manufactured by MB Manufacturing Company, Inc., of New Haven, Connecticut. The shaker capacity is 3500 force pounds with a frequency range of 5 to 2000 cps. Although this unit can be driven by both random and sinusoidal inputs, in the experimentation carried out, it was used solely for sinusoidal excitation. This table also is equipped with an oil-suspended, horizontal table. A photograph of this unit is shown in figure 4.

Either of the two vibration tables described above is driven by a power supply through a console which contains the necessary controls. This console is shown in figure 5. The power supply is a model PP-30/40 manufactured by Ling Electronics, Inc., with a power rating of 30 kva.

A third vibration table, which was used exclusively for preliminary sinusoidal testing, was another model C25H machine, manufactured by MB Manufacturing Company. This unit had a capacity of 5000 force pounds with a frequency range of 5 to 2000 cps. It also was equipped with an oil-suspended, horizontal "slider" table. The power supply is a model 20/20 manufactured by Ling-Calidyne Company with a power rating of 20 kva output.

The response signals of the equipments tested were recorded on two tape recorders manufactured by the Ampex Corporation of Redwood City, California. The first recorder, an FR-1100 Recorder/Reproducer, is a ¼-inch tape machine with two-channel capability. The other recorder, an AR-200 Airborne Recorder, is a one-inch tape machine with seven-channel record capability only. Because of the record only function of the AR-200, another one-inch recorder, the FR-107 Recorder/Reproducer, was utilized to play back the signals recorded on one-inch tape. This tape recorder, also manufactured by Ampex Corporation, has seven-channel record and playback capability. It also was necessary to utilize the FR-107 for making tape loops of the random signals recorded on ¼-inch tape.

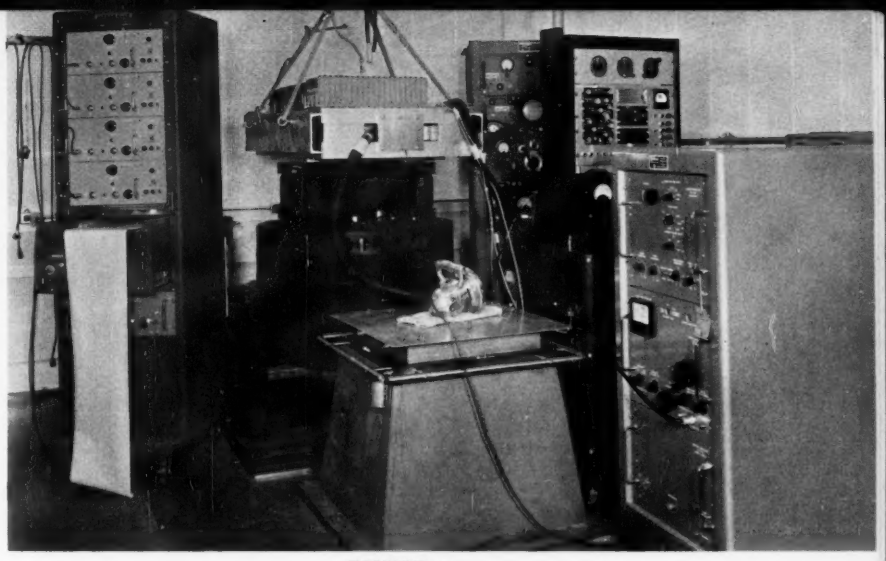


FIGURE 4

Collins 3500-Lb. Vibration Shake Table

In order to analyze the recorded random signals, it is necessary to have repetitive playback of a portion of the signal from a tape loop. Initially, a tape recorder, model LAR3700, manufactured by Minneapolis-Honeywell, was utilized as a tape loop machine by use of tape loop adapters. This equipment was on loan from the State University of Iowa. Later, an FL-100 Recorder/Reproducer tape loop system was placed in operation. This ½-inch loop machine, which can accommodate tape loops of approximately 5 to 50 feet, is manufactured by Ampex Corporation. The FL-100 is equipped with a two-track, movable reproduce head having a maximum displacement of one inch, although this feature was not utilized in the study covered by this report.

The electrical noise signals which were generated by vibration were analyzed on a Honeywell Automatic Wave Analyzer Model 9050. The frequency range which can be covered by this unit is 3 to 10,000 cps. For analysis of a complex data signal, the analyzer can function in a filtered linear or filtered square mode. As an added feature, this unit has two unfiltered modes of operation in which the analyzer functions simply as a recording voltmeter yielding a plot of amplitude or amplitude squared versus time. The filter selectivity is 2/3 to 200 cps. The output of the analyzer is indicated on a Brown Recorder Model 331, which is an integral part of the wave analyzer. The recorder has been equipped with a specil slide wire to give a logarithmic response over a 40-db range covering eight inches on the chart, and a linear response below this to zero output, covering approximately 1⅝ inches. The chart paper is driven so that it will move at a speed exactly proportional to the speed of the variable oscillator in the analyzer.

Test Procedure

Prior to acceptance for vibration testing, all equipments were inspected and calibrated thoroughly by competent personnel to ensure top performance. Then a series of tests were conducted in which the items were subjected to slow sinusoidal sweeeps, at different input levels, to ascertain consistent repeatability of signal degradation. These tests were conducted in three mutually perpendicular axes of the equipment. If an equipment did not appear to have a repetitive degradation of signal in all three planes of excitation, it was rejected from further consideration. Of the many equipments initially, and subsequently selected, only the ARC-70 radio and the approach horizon indicator were considered satisfactory.

In the case of both items tested, the equipment was bolted solidly to the vibration table through the use of special shake table fixtures. A rigorous effort was made to establish a flat frequency response characteristic of the vibration

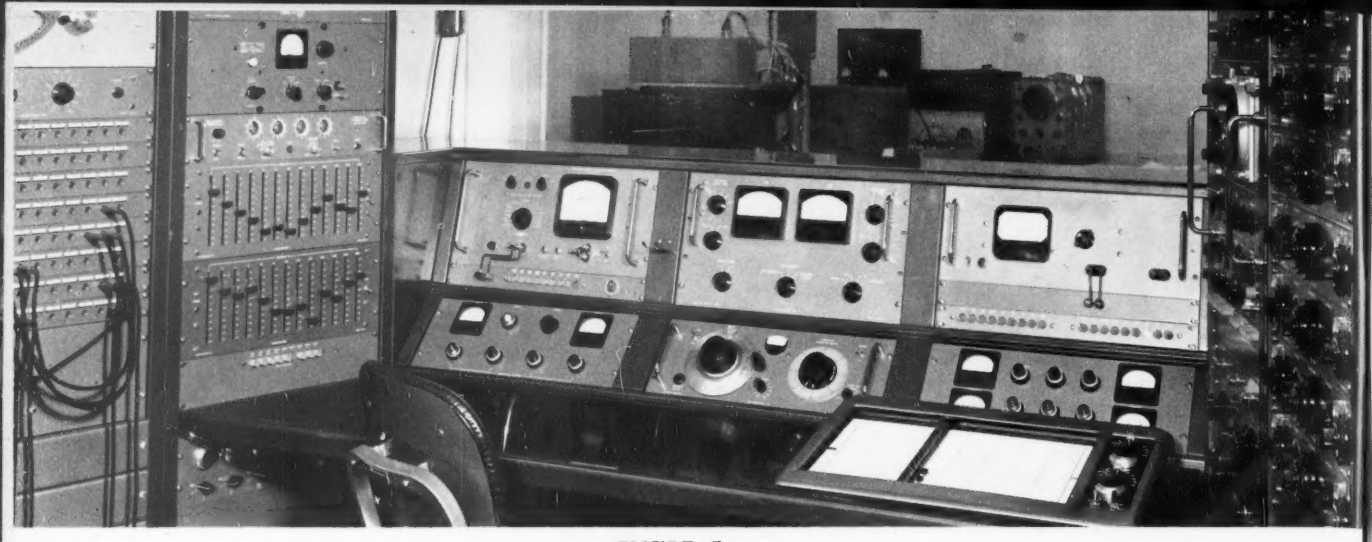


FIGURE 5

Control Console for Collins Random Vibration Facility

table and test specimen. In this test program the system was adjusted as closely as possible to the desired frequency response by using sinusoidal excitation, then the response to random excitation was analyzed on the spectrum analyzer. Below a frequency of 1000 cps the table response was adjusted flat to ± 1 db. In the range of 1000 to 2000 cps table leveling could not be achieved as desired. Typical plots of accelerometer signals analyzed at an effective bandwidth of 3 cps are shown in figure 6. The accelerometers were mounted on the table next to their respective control accelerometers. These typical plots show the equalized input to the equipment on the table.

Upon achieving the desired table equalization, the test specimens were excited with random vibration specified in terms of a value of spectral density, g^2/cps, flat from 20 to 2000 cps. For the ARC-70 radio, seven levels of random input were chosen from .005 to .010 g^2/cps, while the approach horizon indicator was excited at six random levels from .001 to .010 g^2/cps. The output signals of the equipments were observed on a Ballantine Model 320 true rms voltmeter. The signal at each input level was amplified or attenuated, as was necessary, to give an output reading of 250 to 300 millivolts on the true rms meter. The signal then was recorded on ¼-inch magnetic tape for a duration of thirty seconds. After random excitation had been completed in each plane, a sinusoidal test was performed using a very slow cycle sweep at a given peak g level. For both the ARC-70 radio and the approach horizon indicator, five sinusoidal levels of excitation from ¼ to 1½ g's were used. At each level of excitation the voltage of the highest resonant frequency was observed on an rms voltmeter, and the signal then was amplified or attenuated, to give an output reading of slightly less than one volt. The radio signals were recorded on ¼-inch tape, while the indicator meter signals were all recorded simultaneously on one-inch tape.

These tests were conducted in three mutually perpendicular axes of the equipment at each vibration excitation level. Also, during both the random and sinusoidal test runs, a taped recording was made of the output signal of an accelerometer placed adjacent to the control accelerometer. In the case of random excitation, the analyzed accelerometer signals were used to correct the equipment output signal for table characteristics.

It was intended that none of these tests was to cause fatigue damage to equipments therefore the levels of excitation were purposely chosen to be low. However, during testing of the approach horizon indicator, mechanical malfunction of the glide slope flag occurred. This was the only mechanical failure that was encountered.

Method of Analysis

1. RANDOM SIGNALS.

Before any spectrum analysis was performed, a thorough check of the Honeywell Automatic Wave Analyzer was made by Collins laboratory personnel. A signal from a General Radio random signal generator was passed through a Krohn-Hite filter with an bandpass setting of zero to 2000 cps. The voltage level of the signal out of the filter was measured by a Ballantine 320 true rms meter. The signal then was fed directly into the analyzer the output of which is rectified and averaged, then plotted automatically to give a reading of rms voltage versus frequency. The analyzer readout was about 25 percent lower than the measurements taken on the true rms meter. To compensate for this effect, the analyzer readings on random data were mutiplied by 1.35. This method of calibration has been suggested and used by others.[2,3]

To determine the optimum analysis rate for a series of analyzer bandwidths, preliminary tests were conducted with a sinusoidal signal of known amplitude. As a starting point for each bandwidth, the analysis rate dial was set as prescribed in the Honeywell Automatic Wave Analyzer instruction book. The analysis rate then was adjusted until the recorder pen just reached full scale. To be on the conservative side, this rate then was reduced a slight amount to ensure full scale amplitude readings.

The selection of the effective bandwidth of analysis was somewhat arbitrary. A realistic attitude had to be assumed in order to perform the analysis in a reasonable length of time. Two sinusoidal signals, of the same amplitude

REFERENCES

[2] "Shortcomings of Present Method of Measuring and Simulating Vibration Environments," Morrow, C. T., and Muchmore, R. B., Journal of Applied Mechanics, 1955, pp. 369.

[3] "Methods of Computing Equipment Vibration Test Requirements for Measurements of Random Vibrations," W. D. Trotter, Boeing Airplane Company Document No. D-15013, January 7, 1957, pp. 7.

and 10-cps separation, were fed directly into the wave analyzer. These signals were analyzed at effective bandwidths of 60, 30, 15, 3, and 1 cps. The resolution of the two signals was very poor at the 60- and 30-cps analysis. At 15-cps bandwidth, the resolution was improved greatly with the amplitude lower than at the wider bandwidth analyses. The resolution at three- and one-cps bandwidths was very good, and the amplitudes were still slightly lower than those at 15 cps. The amplitudes of the three and one cps were the same, as could be detected by normal observation, and the resolution of the one-cps bandwidth analysis was only slightly improved over that at three cps. The analysis time for a one-cps bandwidth analysis is twice that for a comparable three cps analysis. Taking into account the time requirements to contract completion, effect of tape loop wear, and the degree of resolution necessary, it was decided that a three-cps effective bandwidth of analysis would be the most satisfactory.

All the output signals from equipments, while undergoing random excitation, were recorded on ¼-inch magnetic tape. These taped signals were of approximately thirty seconds duration and were played back through the ¼-inch recorder onto one-inch tape. Tape loops of 15 feet in length were made of each signal which amounts to a sampling time of twelve seconds. Since the table input signal came from a constant source, it was believed that this sample was more than sufficient. The loops then were placed on the Honeywell tape recorder modified with tape loop adapters, and the signals were fed into the automatic wave analyzer. Later in the program, after the arrvial of the Ampex loop machine, these signals were played back directly onto pre-

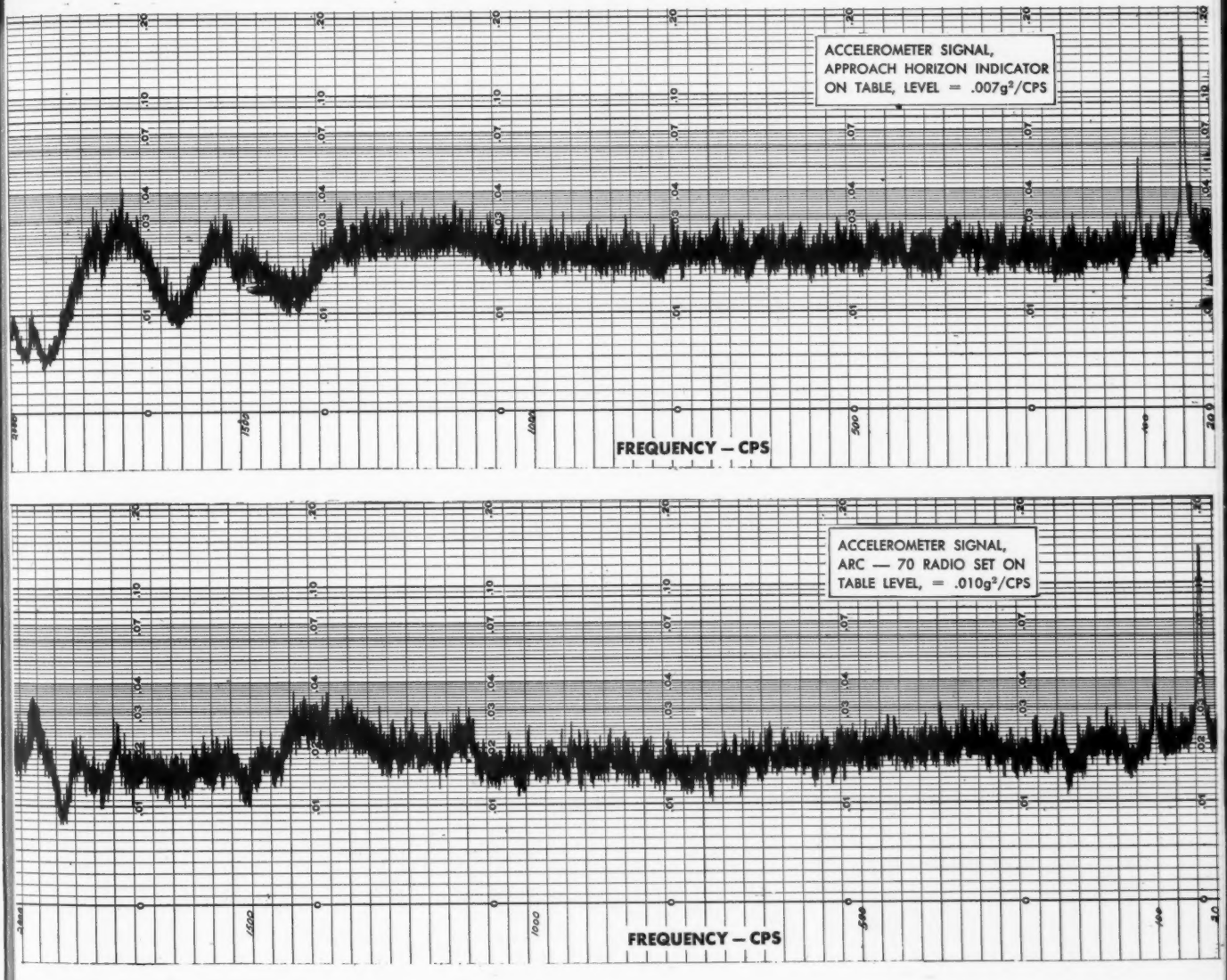


FIGURE 6

Typical Analysis of Accelerometer Signals (Accelerometer Mounted Along Vertical Axis of Shake Table)

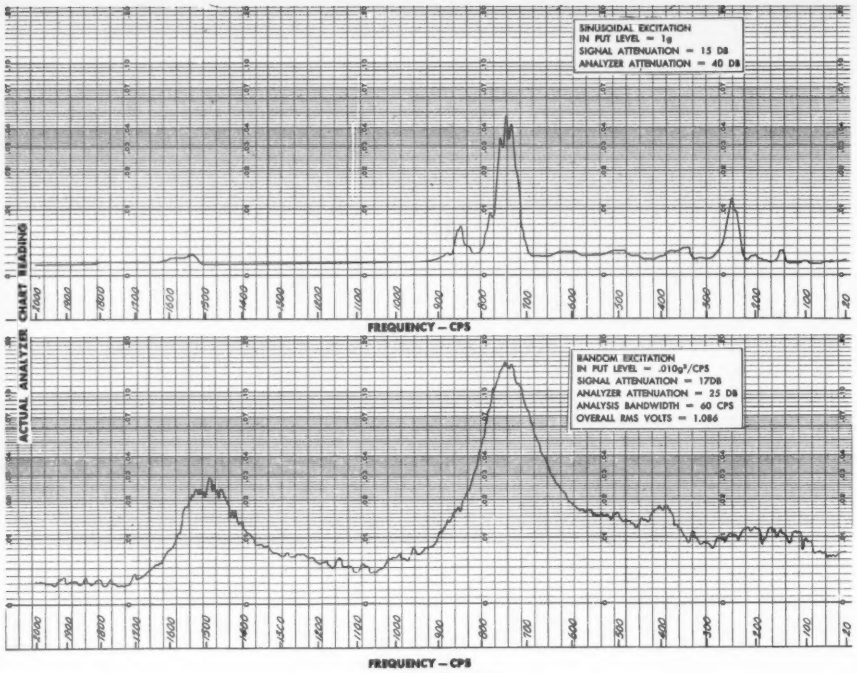


FIGURE 7

Typical Electrical Noise Response of ARC-70 Radio to Sine and Random Vibration (Vibration along Horizontal Axis of Radio)

formed ½-inch loops. All the signal recordings and playbacks were performed at a tape speed of 15 inches per second. The original signal recordings were made on Mylar instrumentation tape of 1.0 mil base. Both the one-inch and ½-inch loops were made of Mylar instrumentation tape of 1.5 mil base and in no instance was any tape loop reused.

To make the most efficient use of available time, the signal on each loop was analyzed rather quickly using an analyzer filter bandwidth of 60 cps. This rough analysis was performed from 20 to 2000 cps to find the general frequency ranges where relatively high amplitudes occurred. Then the signal was analyzed over these selected ranges using the narrow effective bandwidth of three cps. The average time to analyze the recorded output signal on each loop was approximately 2½ hours. The automatic wave analyzer was calibrated before running each loop.

After proper correction, the analyzer trace can be read directly as rms volts versus frequency. The relationship between the spectral density and the analyzer chart ordinate at any given frequency is:

$$G_{f_1} = \frac{1.35\,(Y_{f_1})^2\,(A_c)^2}{BW_e} = \frac{V^2}{cps}$$

where: G_{f_1} = spectral density at frequency f_1, in volts^2/cps

Y_{f_1} = linear ordinate of analyzer chart at frequency f_1 (corrected for gain or attenuation of signal prior to recording), in volts

A_c = attenuation factor of wave analyzer

1.35 = constant required, since analyzer on linear scale reads lower than true rms voltmeter

BW_e = effective bandwidth of analyzer filter, in cps

2. SINUSOIDAL SIGNALS.

A representative sinusoidal sweep recording of the ARC-70 radio and each meter of the approach horizon indicator were selected for examination of the resultant waveform. These signals, which were originally recorded at 15 inches per second, were played back at 1⅞ inches per second and the signal observed on an oscilliscope. At points of resonance the signals of both the radio and meters were found to be sinusoidal in nature. Because of this feature of the output signals, analysis of these long recordings were made relatively easy by using the unfiltered linear mode of the analyzer. In this mode of operation the analyzer functions as a recording voltmeter. When the input signal is periodic in nature the analyzer yields a plot of rms volts versus time of sweep. All the sinusoidal sweep signals recorded in this program were analyzed by the analyzer in the unfiltered linear mode.

Results of Analysis

1. AN/ARC-70 RADIO TEST.

The signal degradation of the ARC-70 radio was reproducible in all three planes, while undergoing both random and sinusoidal excitation. In each of the three planes of the transceiver, the resonance point of highest voltage amplitude occurred at about the same frequency for both random and sinusoidal vibration. Typical plots of the electrical noise response for particular levels of sinusoidal and random excitation are shown in figure 7. In figure 7, the random analysis curve shown is that obtained using a 60-cps bandwidth filter, since no complete plot of 20 to 2000 cps was produced using a three-cps filter. The small peak in the vicinity of 1500 cps on the random excitation plot should be ignored since this is a result of table resonance and the inability to obtain complete equalization of the shaker at the higher frequencies.

Curves were plotted at only those frequencies where the amplitude was less than 10-db down from the highest peak. Table 1 gives a résumé of test results indicating those frequencies at which resonances occurred and compares the amplitude at each frequency to the major or highest peak of each mode of excitation.

2. APPROACH HORIZON INDICATOR TEST.

Each of the meter movements of the approach horizon indicator had different reactions to sinusoidal and random vibration excitation, so the test results of each meter will be summarized separately. Typical plots of the electrical noise response for particular levels of sinusoidal and random excitation are shown in figure 8. In this figure, the random analysis curve shown is that obtained using a 60-cps bandwidth filter since no complete plot of 20 to 2000 cps was produced using a three-cps filter. Tables 2 through 6 give a résumé of test results indicating those frequencies at which resonances occurred and compares the amplitude at each frequency to the major peak of each mode of excitation.

2.1 GLIDE SLOPE INDICATOR.

When the instrument was subjected to sinusoidal vibration in the longitudinal plane, resonance of a marked degree occurred at four frequencies. These resonances repeated at all input levels. At the ¼- and ½-g levels of input, an additional resonance peak of lower amplitude was present which disappeared at the three higher input levels. In the vertical plane there were four resonant points which repeated at all five input levels. At the 1½-g input level, a sharp resonance peak occurred at a point where none was detected before. This peak, at this excitation level, was of the highest amplitude. The spurious peak was ignored in analysis of the results. During excitation in the horizontal plane, resonance peaks at three frequencies repeated at all input levels. Another resonance point occurred at the three highest levels of input but was not distinguishable at the lower two.

During random vibration excitation in the longitudinal plane, five repeatable resonance peaks were detected. At some of the levels a spurious resonance peak would occur occasionally, but these were of lower amplitudes in comparison to the major peaks, so they were disregarded. In the vertical plane very good reproduction of resonance points was obtained at four frequencies. During excitation in the horizontal plane, four resonant points occurred at all input levels. At the three highest input levels, resonance was observed at an additional frequency. This additional peak was of an amplitude comparable to the highest peak at those levels.

In comparing the results obtained from sinusoidal and random excitation in the longitudinal plane, the two major resonance peaks of both methods of excitation were coincidental with respect to frequency. None of the remaining resonance points matched. In the vertical plane again only the two major peaks were at the same frequencies for both sine and random vibration. Frequency correlation of resonance points could not be obtained in the horizontal plane. In fact, the resonance point of highest amplitude for sinusoidal excitation was of very low amplitude during random vibration, and vice versa. (See table 2.)

2.2 GYRO FLAG.

During sinusoidal vibration in the longitudinal plane of the approach horizon indicator, resonances of this meter occurred at four distinct frequencies at all levels of excitation.

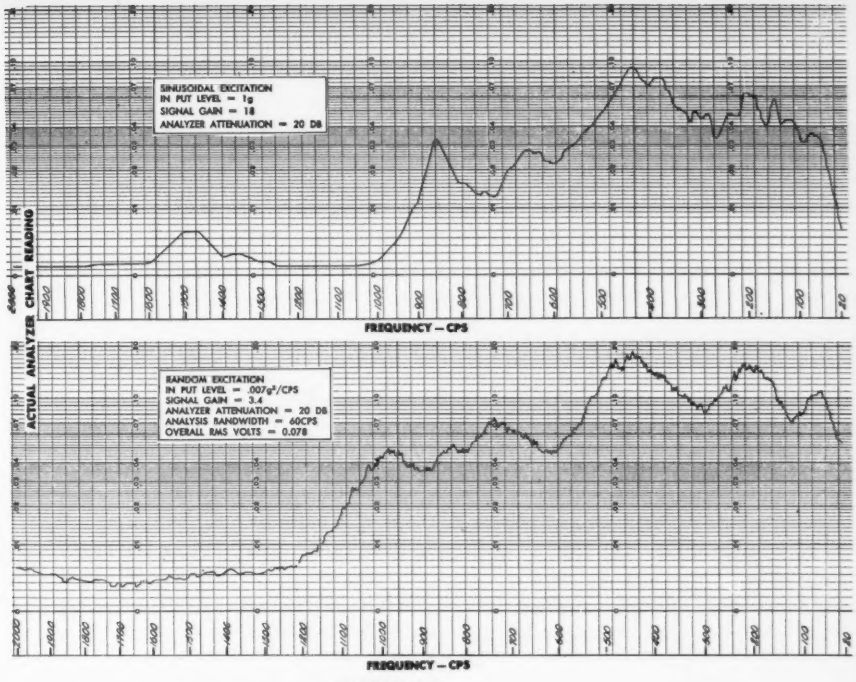


FIGURE 8

Typical Electrical Noise Response of Approach Horizon Indicator to Sinusoidal and Random Excitation (Vibration along Vertical Axis of Indicator)

Another resonance point, which was of relatively high amplitude, was observed distinctly at levels of ¼ through 1-g but was not detected at a level of 1½-g input. In the vertical plane only one resonance peak, which was of the highest amplitude, repeated at all input levels. Two other peaks came into being during the highest three levels while two other peaks at the lowest two levels disappeared. For vibration in the horizontal plane, two resonance peaks, which were the two of highest amplitude, repeated for all levels. Two additional peaks of lower amplitude were detected at lower input levels but were absent from the spectrum trace for the highest input level.

While the instrument was undergoing random excitation in the longitudinal plane, the gyro flag had three resonance points for all levels of excitation. An additional point was detected for all levels except ¼-g. In the vertical plane excellent reproduction was achieved for three frequencies of resonance. Likewise, in the horizontal plane of excitation excellent resonance reproduction was obtained at five frequencies for all input levels.

For obtaining correlation, a comparison of random and sinusoidal results for longitudinal plane vibration indicates poor frequency reproduction from one mode of excitation to the other. The highest peak for random excitation is the secondary peak for sine vibration. For random, at the frequency of the highest sine peak, no peak occurs. No correlation curves could be drawn of the results in this plane. In the vertical plane the primary peaks occurred at about the same frequency for both modes of excitation. The remaining peaks for each mode of vibration did not compare. For vibration in the horizontal plane, the primary peaks of both random and sine were at the same frequency. The remaining peaks again did not compare. (See table 3.)

2.3 STEERING FLAG.

When the approach horizon indicator was undergoing sinusoidal excitation in the longitudinal plane, the response of this meter indicated resonances at five frequencies at all input levels. Likewise, in the vertical plane resonances occurred at four frequencies at all the input levels. During excitation in the horizontal plane, three resonance points repeated for all levels of input. There were additional points of resonance at ¼- and ½-g input but these reduced as the level of excitation increased. Also, these resonances were of low relative amplitude.

During random excitation in the longitudinal plane, excellent reproduction was achieved at eight points for all input levels. (One input level was omitted due to a bad signal recording.) Again, in the vertical plane repeatable resonances were obtained for all five input

PLANE OF VIBRATION	RANDOM EXCITATION		SINUSOIDAL EXCITATION	
	FREQUENCY	DB DOWN FROM* MAJOR PEAK	FREQUENCY	DB DOWN FROM* MAJOR PEAK
Longitudinal	755	0	755	0
	740	1.4	740	2.6
	778	9.4		
Horizontal	740	0	735	0
	753	1.0	741	1.0
Vertical	748	0	746	0

TABLE 1

Resonance Location Correlation of ARC-70 Radio

PLANE OF VIBRATION	RANDOM EXCITATION		SINUSOIDAL EXCITATION	
	FREQUENCY	DB DOWN FROM* MAJOR PEAK	FREQUENCY	DB DOWN FROM* MAJOR PEAK
Longitudinal	850	0	740	0
	768	0	850	4.1
	670	0.4	380	5.5
	80	0.7	300	7.4
	240	1.6		
	475	8.0		
Horizontal	675	0	380	0
	850	0.9	732	9.2
	80	1.3	850	9.7
	240	1.4		
Vertical	435	0	436	0
	240	0.7	236	2.4
	500	2.1		
	750	5.7		

TABLE 2

Resonance Location Correlation of Approach Horizon Indicator Glide Slope

***NOTE:* Amplitudes of all other points of resonance are more than 10 db below major peak.**

***DB down from major peak is meant to show at which resonant frequencies relative amounts of degradation occurred. The signal amplitude at the point of highest degradation in each plane and for each mode of vibration is used as the reference.**

PLANE OF VIBRATION	RANDOM EXCITATION		SINUSOIDAL EXCITATION	
	FREQUENCY	DB DOWN FROM* MAJOR PEAK	FREQUENCY	DB DOWN FROM* MAJOR PEAK
Longitudinal	115	0	844	0
	1100	0.5	112	4.2
	525	0.9	1025	5.9
			480	6.9
			297	8.9
Horizontal	110	0	110	0
	60	3.1	850	0.9
	1100	8.9		
	500	9.7		
Vertical	115	0	104	0
	500	5.5	380	3.5
	1100	8.2	182	5.2
			452	6.2

TABLE 3

Resonance Location Correlation of Approach Horizon Indicator, Gyro Flag

PLANE OF VIBRATION	RANDOM EXCITATION		SINUSOIDAL EXCITATION	
	FREQUENCY	DB DOWN FROM* MAJOR PEAK	FREQUENCY	DB DOWN FROM* MAJOR PEAK
Longitudinal	850	0	880	0
	870	0.8	990	0.5
	100	1.1	1260	1.9
	20	2.2	100	2.7
	120	4.2		
	470	5.0		
	330	7.4		
	60	9.3		
Horizontal	60	0	100	0
	100	0.9	846	6.5
	120	3.1	1296	9.0
	26	5.5		
	850	5.8		
	870	7.8		
Vertical	100	0	102	0
	20	1.0	188	7.8
	120	4.6	440	9.4
	60	6.2		
	830	7.1		
	470	7.5		

TABLE 4

Resonance Location Correlation of Approach Horizon Indicator, Steering Flag

levels. (The sixth level was discarded due to a bad signal recording.) Excellent reproduction of resonances also was achieved for all six input levels in the horizontal plane.

In comparing the responses obtained from sine and random excitation in the longitudinal plane, the major resonance peaks for each mode of excitation are approximately at the same frequency. The remainder of the resonance points do not match with respect to frequency. In the vertical plane, as was observed in the longitudinal plane, only the major peak of each mode of vibration fell at the same frequency. For the horizontal plane the highest peak of both sinusoidal and random excitation occurs at the same frequency. The second highest sinusoidal peak occurs as the fourth highest during random excitation. (See table 4.)

2.4 STEERING POINTER.

During sinusoidal excitation in the longitudinal plane of the approach horizon, the response of this meter did not have reproducibility from one excitation level to the other. In the vertical plane four resonance points repeated for all levels of input. A third resonance reproduced at all levels except 1½-g, and two resonances appeared at only the two lowest input levels. While undergoing vibatory motion in the horizontal plane, eight distinct points of resonance reproduced at the four highest input levels. Only three of these points were present at the lowest input level.

When undergoing random excitation, reproducibility was detected in the longitudinal plane for all input levels, but exact analysis was not carried out at a narrow bandwidth due to failure of reproducibility of sine response in this plane. In the vertical plane five points of resonance are reproduced at the three highest excitation levels. Bad signal recordings of the three lowest levels of input precluded analysis of the lower levels. Four resonance points repeated for all levels of excitation in the horizontal plane while two additional points repeated at the four lower levels only.

In comparing the responses obtained from sinusoidal and random excitation, the longitudinal plane results had to be excluded due to nonreproducibility during sinusoidal excitation. For the vertical plane, the major peak of random and sinusoidal excitation do not

occur at the same frequency. The second highest resonance points compare, but it must be concluded that no correlation exists in this plane. In the horizontal plane, the major peaks fall at the same frequency but the remaining resonance points do not compare. (See table 5.)

2.5 LOCALIZER FLAG.

While undergoing sinusoidal excitation of the instrument in the longitudinal plane, the response of this meter failed to reproduce from one plane to another. In the vertical plane two resonance points reproduced at the four highest levels with only one present at the lowest level. An additional resonance point occurred at only the ¼-g level of input. For vibration in the horizontal plane, three points of resonance repeated at all five input levels while a third point was detected at the four highest levels only.

During random excitation in the longitudinal plane of the indicator, the output signal of this meter showed good reproducibility at all input levels, but narrow bandwidth analysis was not considered necessary since the meter did not have reproducible sine response in this plane. In the vertical plane five resonance points repeated at five input levels. (The sixth level was disregarded due to faulty signal recording.) An additional point was detected at the three lowest input levels. For excitation in the horizontal plane, five resonance points repeated at all six input levels.

Summary and Conclusions

For obtaining correlation, a comparison of random and sinusoidal results for longitudinal vibration could not be made due to failure of the sinusoidal response to reproduce. In the vertical plane, the resonance points do not match from one mode of excitation to the other. The major peaks of both modes of vibration in the horizontal plane do occur at the same frequency. The remaining resonance points cannot be correlated. (See table 6.)

Collins has performed an extensive study of the electrical response of typical avionic equipments while they are being subjected to both random and sinusoidal excitation. These two electromechanical equipments, containing a complexity of mechanical parts, can be considered typical items of avionic gear. The effect of both modes of excitation on both equipments was observed and recorded over a spectrum of excitation levels below the suspected damage level of each equipment. Electrical degradation of the output signal was the criterion used to determine if correlation exists between random and sinusoidal vibration. Some conclusions that have been reached as a result of this test program are:

(1) In all cases an equipment did not appear to have identical response to random and sinusoidal excitation. Generally, the major amplitude peak occurred at the same frequency for both modes of vibration but peaks of lower amplitude did not match. In some instances the highest peak of one mode did not have a counterpart at the same frequency for the other mode.

(2) Low levels of sinusoidal excitation produced higher levels of electrical output than did relatively high levels of random input. In nearly all of the vibration planes of each equipment the electrical signal at ¼-g sine input was higher than the output at a random level of .010 g^2/cps. Previous vibration testing of the ARC-70 Radio Set indicated that a random input of .02 g^2/cps was very severe on the equipment, causing structural damage. No structural damage was observed at a level of 2-g sinusoidal input. Similar results have been obtained by testing other electronic equipments. The results of testing, using electrical degradation as a criterion, do not compare with results of previous testing conducted at Collins using fatigue damage as a basis.

(3) No constant quantity has been found which relates the electrical degradation capabilities of sinusoidal excitation with that of random motion. At those frequencies where there was output signal reproduction from one mode of vibration to the other, the curves cannot be correlated. The slope of the curves of each mode vary with frequency and plane of excitation. The conclusion that must be drawn from the results of the investigation carried out by Collins is that signal degradation cannot be used as a reliable criterion for random-sinusoidal vibration correlation. Further, other work performed by Collins in the area of correlation study using structural fatigue methods does not show promising results either. Therefore, in regard to future studies, neither method can be recommended.

PLANE OF VIBRATION	RANDOM EXCITATION		SINUSOIDAL EXCITATION	
	FREQUENCY	DB DOWN FROM* MAJOR PEAK	FREQUENCY	DB DOWN FROM* MAJOR PEAK
Longitudinal	(No analysis made due to failure of reproduction of sine results)			
Horizontal	119	0	121	0
	211	2.0	255	1.4
	140	3.5	1180	8.1
	1550	4.0	60	8.4
	1600	6.7		
	336	8.0		
	1200	8.0		
	875	9.3		
Vertical	122	0	1175	0
	215	0.2	220	1.8
	452	0.4	110	1.9
	890	3.4	320	3.4
			375	4.5

NOTE: Amplitudes of all other points of resonance are more than 10 db below major peak.

* DB down from major peak is meant to show at which resonant frequencies relative amounts of degradation occurred. The signal amplitude at the point of highest degradation in each plane and for each mode of vibration is used as the reference.

TABLE 5
Resonance Location Correlation of Approach Horizon Indicator, Steering Pointer

PLANE OF VIBRATION	RANDOM EXCITATION		SINUSOIDAL EXCITATION	
	FREQUENCY	DB DOWN FROM* MAJOR PEAK	FREQUENCY	DB DOWN FROM* MAJOR PEAK
Longitudinal	(No analysis made due to failure of reproduction of sine results)			
Horizontal	207	0	210	0
	232	0.6	20	1.3
	75	9.0	975	4.3
			525	5.9
			60	8.7
Vertical	217	0	20	0
	440	10.6	1000	4.7
			200	5.1
			510	6.7
			380	7.0
			750	8.3

TABLE 6
Resonance Location Correlation of Approach Horizon Indicator, Localizer Flag

Test Laboratory of Future

Despite great advances in environmental test equipment, the best laboratory for testing the design and materials for spacecraft is space itself. This is the view of scientists at Ford Motor Company's Aeronutronic Division, Newport Beach, Calif., who are conducting studies of semi-rigid and non-rigid manned space structures for extreme-altitude Air Force weapon systems.

The work is being done under a contract awarded by the Aeronautical Systems Division of the U.S. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, and follows an earlier investigation of rigid space structures.

About the Cover

ARTIST'S RENDERING shows possible applications of expandable structures in space proposed by Aeronutronic Division of Ford Motor Company, Newport Beach, Calif. Structure already in orbit (top) has been expanded to provide laboratory area for space experimentation. The hard-core, command center in front could detach from structure and return to earth once the space laboratory is functioning. Boost configuration at right prepares to rendezvous.

Dr. Seymour Lampert, manager of the Space Systems Aeromechanics Department, who is coordinating the work, said that the design of a manned spacecraft requires information on how various materials will survive in space, plus the ability to fabricate craft that will fulfill their assigned tasks. "We must increase our present capabilities in many areas of technology to cope with the environments in space," he said.

Dr. George J. Mills, manager of the Research Laboratories Materials Department, said the Aeronutronic studies are solving many of the problems, but that they also are leading to new problems which challenge materials technology. "It would be desirable to obtain answers to all our space problems right here on earth, but this is not possible," he said.

"For one thing, we can't always test materials under properly simulated environments, since the significant parameters associated with these environments are not well defined. For another, by the time we are able to build expensive test apparatus, we will have obtained many of the answers from space probes."

He noted that some environmental factors, such as hard vacuum, can be simulated effectively, and will be useful in determining specific materials characteristics.

The Aeronutronic scientists are studying various modular concepts for space structures. A typical spacecraft might consist of a command post or cab up front—a highly secure, rigid structure capable of re-entry. In the center would be a propulsion component containing power for orbital correction or abort, and having a retro-thrust rocket for de-orbit and re-entry. In back would be a living shelter or laboratory structure, packaged within a van module for deployment once in space.

Three general structure concepts are being studied for such a "space train." They are pressure-stabilized membrane structures, rigid-panel inflatable structures of "space shingles," and telescoping modules.

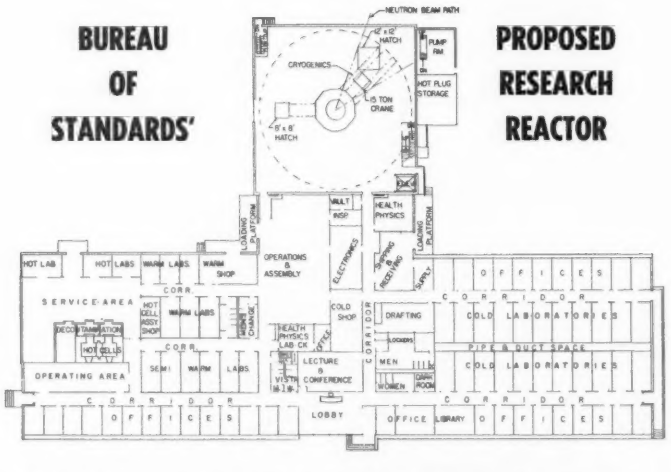
Use of the membrane structures will depend on how well multilayer plastics or rubberized materials can meet conditions encountered in space.

The space shingle concept involves use of panels—curved or flat, interlocking or overlapping—which can supplement flimsy membrane structures and provide necessary armor within a variety of configurations. Sealing of the panels is a problem here.

The telescoping module could be either rigid or semi-rigid, and would be attached to the space cab directly or by a flexible connection. When deployed, telescoped modules would be strung out behind the cab, and could be used as inflated storage compartments or instrumented packages, or as transmitting balloons such as Echo.

BUREAU OF STANDARDS'

PROPOSED RESEARCH REACTOR



A high-flux research reactor is nearing design completion for the National Bureau of Standards' new site at Gaithersburg, Md. The reactor will provide the high-intensity and high-energy fluxes required for the Bureau to establish precision measurement techniques and standards in the reactor field and in areas of basic scientific research. The thermal beams provided will be utilized through the new analytical technique of neutron diffraction to study basic structural properties of matter. Other investigations will be concerned with, for example, radiation effects, chemical analysis, diffusion, and fission. The Bureau will share the use of the reactor with various Government agencies in the Washington area.

MARINE APPLICATIONS OF ENVIRONMENTAL ENGINEERING

By J. S. BROOKS

R.C.A. Victor Company, Ltd.
Manager Environmental Laboratory

What is Environmental Engineering?

Environmental engineering may be defined as "the art and science of designing, testing and packaging a manufactured article to be confident of its ability to function correctly under the environmental conditions it will meet during transportation, storage and operation." To achieve this aim a separate engineering discipline has evolved, supported by special machines, chambers, instruments and methods and practised by specialized engineers and technicians. Their concern is the manipulation of dynamic conditions such as shock and vibration, atmospheric conditions such as temperature, pressure and humidity and other conditions such as electrical stress, corrosion and radiation.

Many of our modern engineering specializations, for instance systems engineering and environmental engineering, are as old as the profession itself. The competent engineer was aware of the service conditions for his design and accommodated them as a part of the normal design procedure. The increasing complexity of mechanisms and the advent of new principles and materials, however, as man moves forward to new activities and demands new heights of performance and efficiency from his machines, have resulted in a vastly increased pool of knowledge to be applied in the production of a modern device. We have reached the stage where the individual engineer cannot know and apply all the scientific factors and resources which influence the product he is designing. In short, this is the age of the specialist.

A group of specialists, under the direction of a leader familiar with many disciplines, forms the design team of today.

Environmental engineering has grown to maturity and takes its part of the responsibility for design. The number of engineers and technicians in this field is small and the facilities are expensive and limited in number. Machines and instruments are available designed specifically for measuring and reproducing physical environments and are grouped together in an Environmental Laboratory. Experience shows that worthwhile economies can be achieved by including allied functions in the terms of reference of the environmental laboratory, such as electrical testing, radio frequency tests, structural testing, standards engineering and instruments calibration. In this way economic use can be made of the facility and staff without increasing overhead charges. This approach generates a facility with broad capabilities and a staff of high calibre.

The environmental laboratory tests a product or material under controlled conditions while monitoring the performance and other characteristics of the specimen. The controlled conditions, or "environmental parameters," may be grouped under the following headings.

Atmospheric Conditions
These include temperature, pressure, altitude, relative humidity, rain, wind, ice, frost, corrosive atmospheres, sand and dust.

Dynamic Conditions
Vibration, shock, impact, steady state acceleration, acoustical excitation.

Radiation
Solar radiation, cosmic radiation, nuclear radiation, magnetic fields, radio fields and other electro-magnetic radiations.

Electrical Conditions
Conditions of electrical stress, arcing, corona discharge, high static potential.

Other Conditions
These include fungus testing, water immersion, static and dynamic physical loading, cooling air simulation.

These conditions can be applied independently, at discrete levels, at various rates of change, and in various combinations, limited by the capability of the machines and ingenuity of the staff. Each condition has a characteristic effect on engineering materials and certain combined conditions produce results which differ from the results of uncombined tests. Engineering judgment is then required to determine whether these results classify the test specimen as acceptable or unacceptable.

Failures under test usually follow a broad pattern and an experienced environmental engineer can sometimes foresee them before testing. Similarly, rectifying modifications can often be suggested by laboratory personnel leading, in some cases, to a redesign based on their recommendations or carried out under their direction.

Applications to Marine Engineering

An interesting method of assessing the value of environmental engineering in the marine field is to consider the matter under four headings: Reliability Analyses, Design and Development, Modifications, and Other Applications.

Reliability Analyses
To demonstrate the power of this sub-

ject, which may be new to some readers, let us take an example of its application in aeronautical engineering.

The specification for an aircraft electronic system might contain a requirement for a probability of survival during operation of 90% for an eighty minute mission. This implies a statistical mean life between failures of 14 hours, based on the Poisson formula:

$$P_s = e^{\frac{-t}{m}},$$

where

P_s = probability of survival

t = time of test (longest mission profile)

m = mean life (average time between failures)

A typical aircraft electronic system might be composed of three sub-systems namely Fire Control, Communication and Navigation, and Flight Control. To meet the complete system mean life requirements, each sub-system would be assigned a mean life between failures as follows:

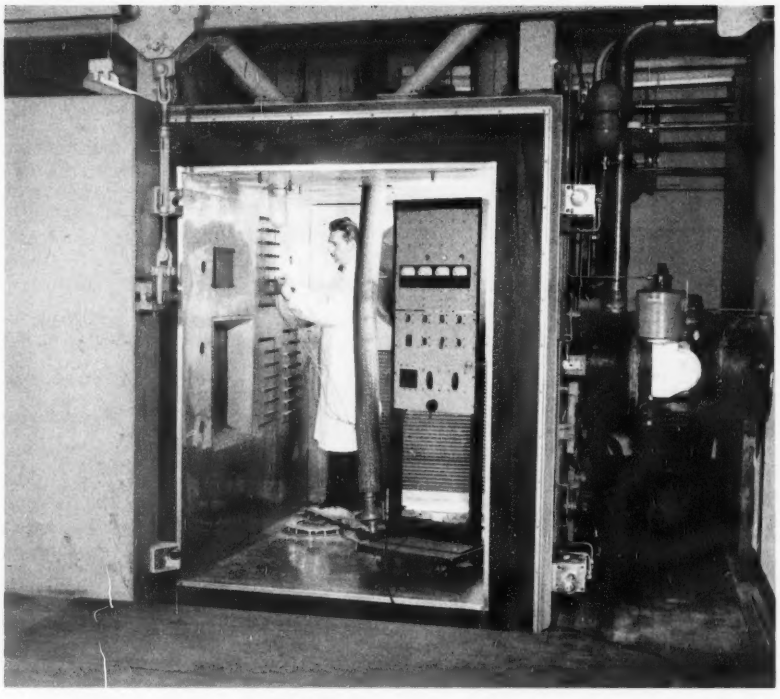
$$\frac{1}{m(\text{System})} = \frac{1}{m(\text{Fire Control})} + \frac{1}{m(\text{Flight Control})} + \frac{1}{m(\text{Comm. and Nav.})}$$

The determination of each sub-system mean life would be based on the complexity of the sub-system in terms of the number and categories of component parts. Sufficient data have accumulated on the failure rates of component parts as a result of laboratory tests and field failure reports to enable a prediction of sub-system reliability to be made from preliminary designs and assumed complexity based on similar existing equipments. Design targets would then be established, test procedures indicated and the probability of meeting the customer's specification evaluated. To complete the example for an advanced airborne system, the required mean life between failures for the sub-systems might be:

Fire Control: 57 hours between failures

Communication and Navigation: 50 hours between failures

Flight Control: 255 hours between failures



Setting up a Test in the Walk-In Stratosphere Chamber. R.C.A. Victor's Environmental Laboratory, Montreal, Canada

High among the factors which directly influence the failure rates of electronic, electrical and electro-mechanical devices are the electrical stress level and the environmental stress level. The aim of the designer is to reduce these stress levels to a minimum and to design new components capable of withstanding higher stress levels with reliability.

The value of this method to the customer is the ability to plan logistics with confidence. The quantity of systems to be purchased to meet an operational requirement, the amount of maintenance manpower required and the spare parts inventory are obvious benefits. Secondary advantages include the provision of a basis for comparing competitive equipment and an indirect ability to push the state of the art in the direction desired by the customer.

The environmental laboratory is intimately concerned with efforts to improve reliability. Component parts and complete systems are developed, tested, approval-tested and quality-controlled through the laboratory's facilities.

What has this to do with the naval

About the Author

Mr. Brooks was educated at Southampton University and Loughborough College, England, and graduated in mechanical and aeronautical engineering. He was commissioned in the Royal Navy in 1942 and held many posts ashore and afloat as an Air Engineer Officer and and Air Armaments Engineer Officer. In his work on naval operational research he was responsible for the introduction of the current concepts of Planned Flying/Planned Maintenance.

He retired from the active list and emigrated to Canada in 1952 and worked on guided missile research and development at the Canadian Armament Research and Development Establishment, where he latterly became Head of the Mechanical Laboratories. He joined RCA Victor in 1957 as manager of engineering services for the Defense Systems Division and was responsible for the design and construction of the new and much enlarged Environmental Laboratory. In addition to managing this facility he is responsibile for overseas technical aid activity and is Project Engineer for an important satellite programme.

Mr. Brooks has published many papers on environmental engineering, missile design, and hydrodynamics. He holds patents on sonar developments, internal combustion engine design, and certain forms of marine propulsion systems. He is a member of the Institute of Environmental Sciences, Institute of Aerospace Sciences and Canadian Aeronautical Institute.

architect and marine engineer? The modern ship is increasing in complexity and improving in performance, particularly the naval vessel, as its task becomes more complicated. For this and other reasons it is also becoming more costly. Not only must the maximum use be made of the vessel but its reliability must be improved, and measured, so that supporting services and operational planning may be placed on an economic basis. Naval authorities, impressed with the improvements in performance and economy achieved in other fields, are considering the application of mathematical reliability techniques to naval vessels. Research into this field, considering a ship as a group of interrelated systems and sub-systems susceptible to evaluation and prediction on a statistical basis, and investigations into the reliability of mechanical components and structures is currently being undertaken in Canada and the United States.

To be successful in the military field, and experience shows that this always reflects into the commercial market, the shipbuilder might in future be asked to predict reliability and show an improvement in this respect over existing vessels. In such an endeavour the use of the specialized knowledge and facilities of an environmental laboratory would be of prime importance.

Design and Development

The design of a piece of equipment is profoundly influenced by the circumstances in which the equipment will live. Consider an electric motor for example. A motor for use in a missile would not be the motor to use in a chemical processing plant or a submarine although the operating principle and output might be the same in all cases. To probe deeper, the method of mounting the motor might also differ, depending upon its location within, let us say, a missile. In one location vibration could be so intense as to require a sophisticated decoupling system while in another location the ambient temperature might call for a special heat transfer mechanism. Similar arguments apply to hydraulics, pneumatics, radar equipment, paints, lubricants and indeed, most engineering materials and structures. The design specification should define these conditions if efficiency and economy are required. The environmental engineer's contribution would be the measurement of these conditions and assistance in selecting components and material, and occasionally in the actual design.

Sound design practice is to perform tests on development models when severe environmental conditions are to be met. In this way faults are removed before the design is "frozen" and production begins. It is better to correct faults in the design stage than to have the customer bring them to one's attention. There is also an economic advantage since the cost of an engineering change on an unreleased drawing and the cost of the environmental tests are together usually less than the cost of changing and reissuing a released drawing and modifying production tooling. Account must also be taken of the cost of possible modification kits or other rework, and the loss of customer goodwill when faults are found and rectified only after sale and installation.

A torpedo component that suffered from galvanic corrosion under high humidity conditions and slackening-off of locking devices under simulated operational vibration and temperature variation is an example of a redesign requirement resulting from environmental testing of a development model. The case of an inertia switch for marine use that showed galvanic corrosion and freezing-up under certain temperature and humidity test conditions may also be cited. Electrical wiring on naval equipment has failed at soldered joints as a result of vibration testing.

Military contracts and an increasing number of commercial contracts call for product approval tests as a condition of acceptance. Usually these take the form of environmental tests on a working specimen and are intended to show the ability of the product to meet the performance specification under extremes of operational environment. This is a qualitative assurance of reliability to the customer. Without environmental tests during design and development a product approval test almost invariably results in failure, and this at a time when correction is expensive and embarassing. This is particularly true of electrical equipment and cases of failure in naval gunnery, communication and navigation equipment are legion. These lessons have taught the electronics industry that environmental tests during development are essential. Aircraft engine manufacturers are another group that, by experience, has arrived at the same conclusion.

Preparing a Test of a Radar Pedestal in a Temperature Humidity Cabinet

Modifications

The use of an environmental laboratory for developing and proving modifications to naval equipment is possibly the most significant marine application at the present time.

Modifications may arise from two sources. First, as a result of user complaints and field failure reports. Marine electronic and electro-mechanical equipment, complicated and not inherently rugged as a rule, normally undergoes a process of modification as failure patterns are established over an extended period of use. This "debugging" period can often be reduced by life-testing a production model on an accelerated time scale in an environmental laboratory before release to the customer. The modifications intended to cure these failures often can be environmentally tested to good effect, before drawing change, tooling and modification kit costs are incurred. A direction-finding antenna mounted on the top of a mast, for example, developed severe vibration of the ground plane rods, leading to fatigue failure of the rods and the near-spearing of personnel on the deck below. An investigation in the laboratory not only located the trouble but quickly provided the solution. The natural frequency of the ground plane rods coincided with the vibrations generated by the ship's screw, the whole amplified by the elastic nature of the mast structure. Increasing the natural frequency of the rods and restraining the cable loops of the receiving part of the antenna to prevent a sympathetic torsional vibration was achieved simply and inexpensively by tests of a complete antenna on an electrodynamic vibrator. The vibration frequencies and amplitudes actually experienced on the ship's mast were reproduced by the vibrator in the laboratory. The final modification in-

creased antenna weight by ten pounds only and did not affect the radiation or receiving characteristics.

Other modifications are intended to improve the performance of a piece of equipment rather than to correct faults. Extending the range of a radar set is an example. It may also be desirable to extend the range of operating temperatures. A mechanical gear box, required to operate in sub-zero conditions, was environmentally tested and showed that a different motor was required as well as changes in oil seals and covers.

An interesting case of this type of modification program concerns a large naval radar. Mounted high on the ship's superstructure, maintenance is difficult in bad weather. An improvement would be gained if an oil could be used in the antenna pedestal that requires less checking and is suitable for very low temperature operation. The procedure used was to test selected oils in a pedestal under simulated shipboard environments.

Calculations were made of the weight of the antenna sail with severe icing. The cyclic torque loading on the driving shaft due to the varying aerodynamic drag in a wind of 60 knots was also estimated. A test-rig comprising a plastic-covered box containing sandbags weighing several hundred pounds and a system of lead weights lifted and lowered sinusoidally to represent the cyclic torque was installed in a large environmental chamber and attached to an antenna pedestal lubricated with the oil under evaluation.

The chamber was programmed to produce a repeating cycle of temperature ranging from 160°F to —80°F, with variable relative humidity to reproduce measured conditions in the tropics and arctic regions. Added realism was achieved by rain sprinklers operated at certain periods. The temperatures of bearings, motor, structure and lubricating oil at several critical points were monitored continuously.

The test of each oil lasted several weeks without planned stops. Samples of the oil were taken at regular intervals and analysed for water content, acidity and foreign matter.

Oils which successfully passed the climatic test were then tested in a loaded, operating pedestal under simulated shipboard vibration, again with simultaneous temperature variation. A suitable oil was selected in a few months at a cost of a few thousand dollars. It is interesting to note that several failures took place in the pedestal itself which investigation showed had occurred on board ship but had not been officially reported. The modifications to cover these cases were also completed. The end result was an antenna needing less maintenance and capable of operation in all naval circumstances with improved reliability.

The repair and overhaul of complex naval equipment on a contract basis affords another use of the environmental laboratory. The testing of a statistically selected proportion of the output of overhauled equipments becomes a powerful quality control procedure and points up changes in workmanship, inferior components and material, and occasionally by inducing unexpected failures, the need for new modifications.

Other Applications

The compilation of specifications for many purposes, such as design, test, performance, procurement, component parts and materials, based on measurements of actual operational environments forms an important part of the environmental engineer's work. This type of specification becomes more important as stress is placed upon reliability, minimum weight and economy.

Experimental stress analyses, using strain-gauges and stress sensitive coatings, under static and dynamic load conditions are carried out by more experienced facilities both in the laboratory and on field location. A large structure subjected to wind and ice loads was surveyed by instruments and the loads calculated. These were used to test a statically loaded production version in the laboratory. Strain-gauges were employed to measure the stresses in the structure thus enabling the adequacy or otherwise of the design to be determined. Small boat hulls are tested in a similar manner, under dynamic conditions, by applying shock loads to a specimen mounted with strain-gauges.

Large ship structures showing excessive elasticity under high wind and sea conditions are surveyed with strain gauges. Examination of the results indicates where additional structure should be added and the required strength for the new members.

Corrosion studies are also possible in an environmental laboratory. The effects of marine atmosphere and spray can be reproduced with tolerable accuracy on an accelerated time scale, enabling the efficiency of paints, other finishes and hermetic seals to be measured on a comparative basis. The investigation of galvanic corrosion, a frequent offender, can also be undertaken. New materials can be tested for marine suitability, as well as plating techniques for metal protection, electrical components such as plugs, switching gear, junction boxes, cables and waveguide for marine radar.

Vibration and acoustical surveys are carried out where stress levels are high enough to cause material failure or degradation of human performance. Vibration surveys can be important in those areas where delicate electronic equipment is installed since it is probably true to say that vibration is the largest single cause of failure in electronic and electro-mechanical equipment. The results of these surveys are translated into the selection or design of decoupling systems. Acoustical energy is vibration transmitted through the air rather than the structure and produces similar effects. Acoustical surveys need more equipment than vibration surveys if complete data are required, although simple instruments can be used for the "quick look" approach. The reduction of high ambient noise sometimes requires fairly extensive modifications and is an example of the precept that prevention is a lot cheaper than the cure. In most practical cases both types of excitation exist and interact upon one another. A better understanding of vibration and acoustical phenomena by the designer is needed and would result in improved performance by men and machines, as well as saving sizable sums of money in modification engineering.

An application closely related to the vibration survey is the Noise Reduction Program. Noise generated in and by a ship usually falls within the frequencies efficiently transmitted through water. Thus an excellent signal is provided for detection by enemy surveil-

Continued on page 30

MEETING ANNOUNCED ON SHOCK, VIBRATION

The Office of the Director of Defense Research and Engineering has announced that the 30th Symposium on Shock, Vibration, and Associated Environments will be held at the Statler-Hilton Hotel in Detroit, Mich., Oct. 10-12.

The Detroit Army Ordnance District will be host to the meeting.

Two subject areas have been selected, "Extreme Operational Environments" and "Transportation and Packaging Environments." These will be covered in parallel sessions.

Institute of Environmental Sciences
Membership Requirements

Qualification requirements
The following quotations from the IES By-Laws state the qualification required for the various grades of personal membership in the Institute of Environmental Sciences.

Grade of Associate Member:
An applicant for the grade of Associate Member shall be:

(a) A graduate of an accredited institution of higher learning, or

(b) A person regularly employed in the field of environmental engineering or its branches, or

(c) A full-time teacher of engineering subjects who cannot meet the experience requirements for the grade of Member, or

(d) An executive or administrator of engineering, technical, or manufacturing work who cannot meet the requirements for the grade of Member.

Minimum Requirement for Grade of Associate Member
Experience: Degree in engineering or sciences, or one (1) year applicable practical experience of a technical nature in the field of environmental engineering or its allied branches. Time spent at an accredited engineering college on a non-degree full-time basis may be used to partially satisfy the one-year requirement.

References: An applicant for the grade of Associate Member shall furnish references from three (3) members of the Institute at least one of which shall be a Member or Fellow and two of which may be Associate Members. **This general requirement may be waived or modied for good cause by the Membership Committee at their discretion, upon application by a prospective candidate.**

Grade of Member:
An applicant for the grade of Member shall be:

(a) An engineer or scientist working in the field of environmental engineering or its allied branches, or

(b) A full-time teacher of engineering subjects in an accredited engineering college or institution of higher learning, or

(c) An executive who has under his direction important engineering or technical work related to the fields of environmental engineering or its allied branches, or

(d) An Associate Member for five years in good standing.

Minimum Requirements for Grade of Member
Professional Experience: A total of 9 years experience in the applicable category (above), including time spent at an accredited institution of higher learning in pursuit of a degree in engineering or the sciences. At least five years of the total must have been spent in active engineering practice.

References: References in behalf of a candidate for the grade of Member are required from two (2) Fellows of the IES and three (3) Members. **This general requirement may be waived or modified for good cause by the Membership Committee upon application by a prospective candidate.**

How much IES membership costs
Annual dues are based upon the month in which the member's application is received.

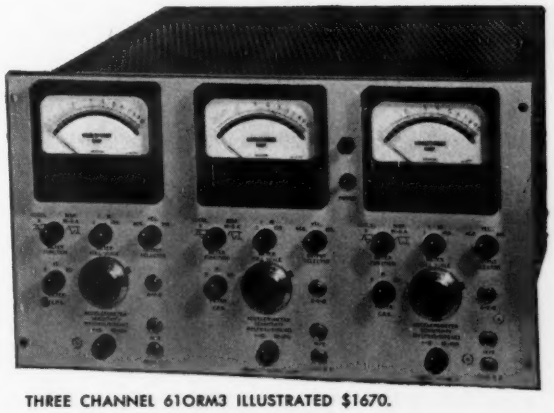
Annual dues for membership are shown on the following schedule.

Classification	*Annual Dues*
Associate Member	10.00
Member	15.00

Applications can be obtained from the National Director located in your area (see page 3) or **Mr. Herbert Saunders,** Membership Vice-President, c/o Vap-Air, 6444 W. Howard St., Niles 48, Illinois.

vibration meter displays displacement or "G" from any accelerometer

The new UNHOLTZ-DICKIE Double Integration Vibration Meter, Model 610, indicates displacement or acceleration from any piezoelectric accelerometer—data is standardized—with minimum chance of error. Each channel allows simultaneous monitoring of displacement, velocity and acceleration. A calibrated dial automatically normalizes all outputs when set to the input accelerometer's sensitivity—giving 1 volt rms/g, 1 volt rms/in DA, and 96.4 mv (rms)/in/sec (rms). High input impedance eliminates need for external cathode follower. Each channel has 25 feet of driven shield input cable. Six models available—bulletin and prices on request.



THREE CHANNEL 610RM3 ILLUSTRATED $1670.

Another product from Unholtz-Dickie, manufacturers of complete calibration and vibration test systems.

UNHOLTZ-DICKIE CORPORATION 2994 Whitney Avenue, Hamden, Connecticut

STEERING COMMITTEE MEETS

The newly proposed Orange County Chapter Steering Committee met recently to adopt by-laws and consider officers for their chapter. Their by-laws have been submitted to the National Executive Committee for approval. This chaper is expected to be approved at the next National Executive Committee meeting on October 9, 1961 in Detroit, Michigan. The officers of the Steering Committee are: Chairman, Bob Inabinatte—Pacific Scientific Company, Co-Chairman, Jack Morgan—Aeronutronic, Secretary, Jerry Kanen—Servonic Instruments Inc., Treasurer, Ken Hagen—Robertshaw-Fulton, Membership Chairman,John Finazzo—American Laboratories, Program Chairman, Don Dickey—American Laboratories, By-Laws, Harry Coolidge—Ling Electronics, Booster, Phil Dodd—Cadillac Gage. This meeting was held in Fullerton, Calif.

LOCAL CHAPTER NEWS

In lieu of Local Chapter News we are issuing the reports presented by the Chapter Directors at the National Executive Committee Meeting held in Los Angeles on July 8, 1961.

BOSTON Chapter. No representative at the Executive Committee Meeting.

CHICAGO Chapter. Reported by Mr. John Losse that the officers met on May 25th for a meeting to formulate future programs. They are planning to have a representative in Mishawaka, Indiana as they have had in Rockford and Milwaukee, during last year. They also expect to have meetings in Rockford, Milwaukee, and Mishawaka. They have 93 members and will plan 8 meetings for the coming year.

MICHIGAN Chapter. Reported by Otto Altman. He stated they had Neal Granick in June and planned to have Brig. General Donald Fleckinger for their September meeting.

LOS ANGELES Chapter. Mr. Bruno Forsher stated they had a meeting in June and a speaker from U.S.C. who spoke on human engineering test under high acceleration on the body.

MID ATLANTIC Chapter. No representative at the Executive Committee meeting.

NEW YORK Chapter. No representative at the Executive Committee Meeting. Information has been received there is a meeting planned for September 21st covering "HYGE Shock Testing Problems."

NORTHWEST Chapter. Mr. James Stuart reported. They have increased their membership from 40 to 50 and are considering a college course at the University of Seattle. One meeting is planned for every other month.

NORTHERN CALIFORNIA Chapter. Mr. Curtis Seyler reported. They have increased their membership from 63 to 70, a newsletter is planned to go out one month prior to the programs and they have a program every two months. Their last meeting was at Lockheed Aircraft. A meeting is planned for October 2, 1961 on "High Altitude Simulation Testing for both Liquid and Solid Propulsion Systems."

SAN DIEGO Chapter. No representative at the Executive Meeting.

SOUTHERN TIER. Mr. Ralph Meza, National Director, reported they will have a planned tour at C.E.C. for their next meeting. They are also helping Rochester, New York to start their chapter.

SOUTHERN OHIO Chapter. No representative at the Executive Committee Meeting.

CENTRAL NEW YORK Chapter reported, through Murray H. Epstein, they will have their application for charter ready in the very near future.

COLORADO Chapter has filed their application for charter with the Local Chapter Vice President, Gary Doering. Their provisional officers are: President, Howard McGregor—The Martin Co., Vice President, Harry Williamson —Beech Aircraft Co., Executive Secretary, Terry O'Grady—Power Sources Inc., Recording Secretary, Al Iadarola — The Martin Co., and Treasurer, George Zawadski—Stanley Aviation.

NATIONAL CAPITAL Chapter has presented their by-laws to the Executive Committee for approval. These have been forwarded to the Local Chapter Vice President, for further discussion with the Chapter Steering Committee.

TWIN CITIES Chapter is gaining strength. Mr. Ernest L. Woodfill of the Environ Electronic Laboratories, Minneapolis, Minn. is the man to contact in this area.

ENVIRONEWS

This column is newly created to supply the readers with news items of general interest. Topics to be covered will be: Abstracts, Book Reviews, Education, Facilities, Member's News, New Products, Publications, and Services.

ABSTRACTS

ENVIRONMENTAL PHYSICAL STANDARDS

By Joseph W. Burgess

The project outlined in this paper was initiated to relate the conditions produced by environmental testing equipment directly to the Bureau of Standards to a known degree of accuracy. The term *Environmental Physical Standards* was chosen to represent physical standards of sufficient accuracy o accomplish this task. The physical quantities standardized in this project are temperature, relative humidity, absolute pressure, and mechanical vibration.

Emphasis on a clear and consistent method of calculating uncertainties permitted definite statements concerning the probability of the occurrence of deviations outside the stated limits. Typical instrumentation for measuring environmental conditions was evaluated using these standards; and the degree of success with which the instrumentation met the applicable military specifications was determined.

Obtainable in the 1959 Meeting Proceedings.

AN ACCELEROMETER WITH A MECHANICAL DAMPER

By V. S. Shatrov (U.S.S.R.)

In order to dampen possible oscillations arising from non-measurable accelerations a screw is used in place of a spring and small load as oscillation damper. The screw, creating a tension condition, does not permit the sensitive system of the device to enter into oscillations as the result of accidental accelerations below the measureable ones.

A copy of this paper is available from the Office of Technical Services (#61-21968), Department of Commerce, Washington 25, D.C. $0.50

BOOK REVIEWS

Satellite Environmental Handbook: Johnson, Francis S. (Stanford, Calif., Stanford Univ. Press) $5.50

A handbook compiled by LMSC scientists for persons working in space systems, geophysics and related fields, has been published by the Stanford University Press.

Titled "Satellite Environment Handbook," it was edited by Dr. Francis S. Johnson, manager of space physics research. Contributors, besides Johnson, were Drs. A. J. Dessler, W. B. Hanson, and J. F. Vedder of the space physics organization, and Dr. O. K. Garriott, consultant.

The handbook contains probably the most complete and comprehensive summary of data describing the geophysical environment encountered by artificial earth satellites, Dr. Johnson said.

It is designed as a convenient reference for persons working on research and engineering programs in space systems development, geophysics, meterology, communications and related fields.

Data is presented on the structure of the upper atmosphere and the ionosphere, penetrating particle radiation, solar radiation, micro-meteorites, radio noise, thermal radiation from the earth and geomagnetism.

Dr. Johnson said, "It is felt that the data presented in this volume should be acceptable as the most realistic information that can now be assembled."

VIBRATION CONTROL: MacDuff, John N. and Curreri, John R. (New York: McGraw-Hill, 1958) 465 pages $9.75.

The authors strike a happy balance for the environmental engineer concerned with the design and analysis of components and fixtures intended for use in environments of vibration, shock or acoustical noise. Following an introduction which fortunately gives wider publication to the American Standards Associations Shock and Vibration Terminology, some basic theory is presented in single and multi-degree of freedom systems. Upon this base, the authors build a discussion of vibration isolation, mechanical transients, shaft vibrations and torsional vibration. A chapter each is devoted to Sound and Noise Control and automatic-control systems. An appendix contains a discussion and example of numerical analysis of non-sinusoidal wave forms.

The treatment offered in this text, written equally for students and practicing engineers, includes many powerful analytical tools missing from earlier works. The Impedance Method is discussed and illustrated in several examples. Non-linear systems are analysed by the Duffing, Schwesinger, and Phase-plane Delta Methods, the unique advantages and limitations of each being stressed. When unfamiliar concepts, e.g. Beta and Gamma functions, are introduced, a brief but welcome explanation is offered. The analytical treatment of transients is supplemented by a discussion of analog computer operation and techniques as applied to the problem of shock excitation.

The chapter on Sound and Noise Control will probably be of limited usefulness to the environmental engineer engaged in producing an acoustical environment. Concepts of noise production and transmission are not treated by the authors. Similarly the control system discussion will be of greater interest to designers of Servo-systems, although the application of the techniques discussed to closed-system vibration testing will shed light on the often-baffling problem of system response time vs. time to peak-acceleration encountered in swept spectrum tests.

A challenging study and valuable reference, this text will provide the environmental engineer with greater understanding of the problems involved with testing to higher service requirements, greater frequency range and more sophisticated environmental control specifications.

This book review was written by **Douglas G. Dwyre,** Senior Research Engineer, Lockheed Missiles and Space Company.

EDUCATION

SONIC EXPERIMENTAL KIT

An unusual set of specially-developed, high-precision appartus will enable laboratories of all types and institutes of learning to study sonic phenomena and its applications.

Called the "Astro-Lab," this unit has been developed as a "service to science and industry," by Astrosonics, Inc., Syosset, N.Y. according to John Perkins, president.

The apparatus is contained in a special-

ly designed permanent carrying case which is provided with suitable cushioning to prevent damage.

Complete information may be had by writing William Fortman, Director of Research, Astrosonics, Inc., 190 Michael Drive, Syosset, Long Island, N.Y.

LECTURE SERIES

The Northern California Chapter announces the start of their Environmental Engineering Lecture Series. The lecture series is being offered in conjunction with the University of California Extension Division. This will be a sixteen week course conducted at two locations, Lockheed Aircraft Corporation Auditorium in Palo Alto, California, and Aerojet General Corporation Auditorium in Sacramento, California. Mr. **Curt Seyler** of Aerojet General Corporation will be the Sacmento coordinator and Mr. **John P. Campbell** of the Philco Corporation will be the Palo Alto coordinator.

The speakers and their topics are as follows:

"The Role of Reliability in Environmental Testing"
Leslie Ball, *Boeing Company*

"Upper Atmosphere and Outer Space Environment"
W. B. Hansen, *Lockheed Aircraft Corporation*

"Vacuum Technology"
Charles Hunt, *Temescal Metallurgical Corporation*

"Space-Thermal Simulation"
Morris W. Rubesin, *Vidya, Incorporated*

"Low Temperature and Cryogenics"
F. C. Hurlbut, *University of California*

"Re-Entry Simulation"
Jackson R. Stalder, *Vidya, Incorporated*

"The Spaceman and His Environmental Requirements"
Robert S. Pogrund, *Aerospace Corporation*

"Fundamentals and Theory of Mechanical Vibrations"
D. H. Young, *Stanford University*

"Vibration Testing"
Karl Unholtz, *Unholtz-Dickie Corporation*

"Shock Induced Motions"
R. F. Steidel, *University of California*

"Acoustic Environments"
W. D. Burton, *Burton Company*

"Instrumentation for Dynamic Measurements"
Irwin Vigness, *U.S. Naval Research Laboratory*

"Radio Frequency Interference"
W. R. Vincent, *Stanford Research Institute*

"Storage and Transportation Environments"
D. J. Missimer, *Missimers, Incorporated*

"Test Specification and Procedures"
Neal Granick, *NASA Goddard Space Flight Center*

"Test Management and Operation"
William L. Vandal, *Ford-Aeronutronic*

Any comments or suggestions readers may have concerning the Educational activities of the Institute of Environmental Sciences should be directed to Mr. **William Vandal,** Chairman Education Committee, Institute of Environmental Sciences, P.O. Box 191, Mt. Prospect, Ill.

OZONE COURSE TEACHING KIT

New from Ozone Research & Equipment Corporation, 3840 N. 40th Avenue, Phoenix, Arizona, is the O_3Q Ozone Teaching Kit. The O_3Q Kit consists of an Ozone Generator. plus an 8-page booklet setting forth instructions for demonstrations and experiments as well as important source references.

While the O_3Q is designed to provide a visual demonstration of the production and effects of ozone for the science class, it can also be used for research having an output of 0-20,000 pphm/volume of ozone.

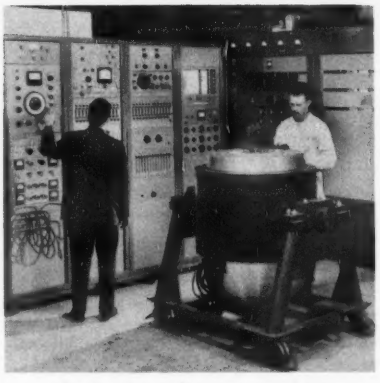
FACILITIES

HIGH VACUUM

Rototest Laboratories in Lynwood, Calif. announce the addition of a six inch diffusion pump facility with ion guage capable of taking various chambers to an ultimate vacuum of 10^{-6} millimeters of mercury. This newest phase of facility augmentation marks the beginning of a long range expansion program.

HIGH FORCE VIBRATION

Wyle Laboratories' Parameters Division, Westbury, New York, has acquired a new, advanced vibration system which meets the test requirements of the latest and most powerful missiles, such as Titan II.



The system includes a 50 KW Ling amplifier, Model PP 50/70, a Ling Model ESD-20/ASD-20 spectral density equalizer/analyzer which permits continuous and parallel observation and control of spectrum in random vibration test programs, and a Ling A246 vibration exciter shaker rated at 7500 pounds force.

MEMBER'S NEWS

HAL GILMORE

Endevco Corporation, Pasadena, California, electronic instrumentation firm, announces the appointment of **H. N. "Hal" Gilmore** as Field Engineer to work out of the Gates Mills (Cleveland), Ohio office.

Mr. Gilmore has a diversified technical background having worked as sales engineer for Powers Regulator Co., Cleveland; district sales manager for the Midwest with Aeronautical Division of Robertshaw-Fulton of Anaheim; and was with the environmental lab of Goodyear Aircraft in Akron, Ohio.

Continued on page 26

ELECTION OF FELLOWS

Mr. Mark Christensen and **Mr. Norman A. Ponge** have been awarded the Institute of Environmental Sciences grade of Fellow by the National Executive Committee.

Mr. Mark Christensen received his B.S.M.E. from the University of Illinois and has had additional studies in Vibration Theory and Electronics.

Mr. Christensen has spent the last ten

MARK S. CHRISTENSEN

years on the West Coast with North American Aviation, The Firestone Company, Nortronics and Wyle Laboratories handling all phases of environmental testing. He is presently with the Aerojet General Corporation of Azuza, Calif.

Mr. Christensen was one of the initial group of men assisting in the formation of the former organization known as the "Society of Environmental Engineers." He first served in the capacity of Chairman of Education & Publicity and Newsletter Editor. Next, he was appointed Program Chairman. The following year, he was elected Vice President, and in that position, assisted in the merger of the S.E.E. organization into the I.E.S. Since the merger, he has twice been appointed Director from the Los Angeles Chapter to the National Board. Recently, Mr. Christensen was appointed Chairman of the Committee for Education, assigned the task of establishing a training course in Environmental Testing in cooperation with one of the local universities.

Mr. Christensen is presently the National Fiscal Vice President of the Institute of Environmental Sciences.

Mr. Norman A. Ponge has attended the Brooklyn Polytechnic Institute, studied at Queens College and taken courses in Mechanical Engineering at other local universities. He has spent thirteen years in the testing laboratory business as Manager of the Environmental Testing Group in New York City and three years as Vice President in charge of operation of Burgoyne Testing Laboratory in Westbury, Long Island. In January 1959 he formed "Space-Tron-

NORMAN A. PONGE

ics, Inc." a manufacturers representative organization.

Mr. Ponge has served as Chairman of the New York Chapter for the past year and is now the National Director for this chapter. He has filled various chairmanships for the New York Chapter Symposiums. He was the Exhibit Chairman for the 1961 Technical Meeting and Equipment Exposition. He is again the Exhibit Chairman for the 1962 Meeting which will be held in Chicago next April. He is a member of the Society of Non-Destructive Testing, American Society of Metals, and the American Ordinance Association.

BETHLEHEM EXPANDS

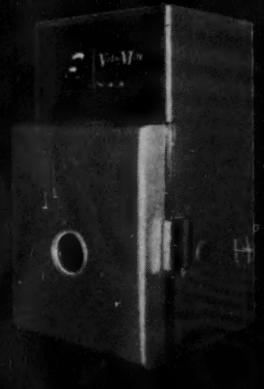
ENVIRONMENTAL ENGINEERING DIV.

Now offers the industry's widest range of environmental test equipment for every military, industrial and research requirement.

ValuLine

ECONOMY SERIES

Standard Production, temperature, temperature-altitude and humidity models offering important features of larger, more costly chambers.



ValuMite

- "Off-the-shelf" deliveries to you.
- 2 cu. ft. test space.
- Temps from —100 °F to +240 °F.
- Ind. temp. controller ±1° C temp. tolerance.
- Key-locked chromed door latch.

Write for Bethlehem's complete environmental product catalog

BETHLEHEM CORPORATION

225 W. SECOND ST., BETHLEHEM, PA.

ENVIRONMENTAL ENGINEERING DIV.

OTHER BETHLEHEM PRODUCTS: CHEMICAL PROCESS EQUIPMENT, CEMENT MILL MACHINERY, SPECIAL MACHINERY, AUTOMATIC HEATING EQUIPMENT; FOUNDRY, FABRICATION AND MACHINE SHOP SERVICES.

FRED HERMANN

Tenney Engineering, Inc., of Union, N. J., a major manufacturer of environmental and orbital simulators, has organized a West Coast division at South Gate, Calif., with **Fred Hermann,** veteran Tenney special projects engineer, as manager.

The division will be based at the Harvick Manufacturing Corp., recently acquired by Tenney, and Mr. Hermann has also been named a vice president of Harvick, which designs and manufactures missile and airplane handling equipment.

PUBLICATIONS

CORRECTED OPTICAL PYROMETER READINGS

By D. E. Poland, J. W. Green, and J. L. Margrave, National Bureau of Standards Monograph 30, issued April 21, 1961, 74 pages, 55 cents. (Order from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D.C.).

This table enables optical pyrometer users to convert immediately the observed temperature to the true temperature, taking into consideration the effective emissivity of the observed material. Conversely, the table can be used to determine the effective emissivity if the true temperature is known, by comparing this temperature with the pyrometer reading.

BIBLIOGRAPHY OF TEMPERATURE MEASUREMENT

January 1953 to June 1960, by Carl Halpern and Robert J. Moffat, National Bureau of Standards Monograph 27, issued April 6, 1961, 13 pages, 15 cents. (Order from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D.C.)

More than 500 references to the field of temperature measurements are presented in this monograph, which was compiled in cooperation with the AE-2 Committee, Physical Measurement Sensing, of S.A.E.

These references, covering the period from January 1953 to June 1960, with some earlier entries, were collected from two general sources: scientific and technical literature and government reports.

Some references to calibration of instruments, and to scientific theories on which temperature measurement is based, are also included. One section discusses "nuclear applications of temperature measurement," and the last section presents "associated equipment and testing procedures."

ACCELEROMETERS TECHNICAL BOOK

The Fourth Edition, 1961, of the revised Endevco 2200 Series Accelerometers Technical Book has been released by Endevco Corporation, Pasadena, California. Originally published in 1959, the latest edition incorporates many revisions to supply the latest state-of-the-art data for environmental engineers interested in vibration and shock instrumentation.

Table of Contents offers discussion of Applications, Piezoelectric Materials, effects of Non-Vibration Environments, Mounting Techniques for Transducers, Fixtures, Uses of Piezoelectric Accelerometers for Shock Measurements, Calibration Techniques, Maintenance Data and useful formulae.

For copy of this book address inquiries to Literature Department, Endevco Corporation, 161 East California Boulevard, Pasadena, California or phone SYcamore 5-0271.

THE ADMINISTRATIVE CONTROLS OF CONTRACT RESEARCH FOR INDUSTRY

A descriptive statement prepared by Battelle Memorial Institute—is now being offered to representatives of industry concerned with research and development. The statement is one of a series on the procedures and characteristics of contract research for industry which is being published by the Columbus, Ohio, research center.

The statement describes the balance of

Continued on page 28

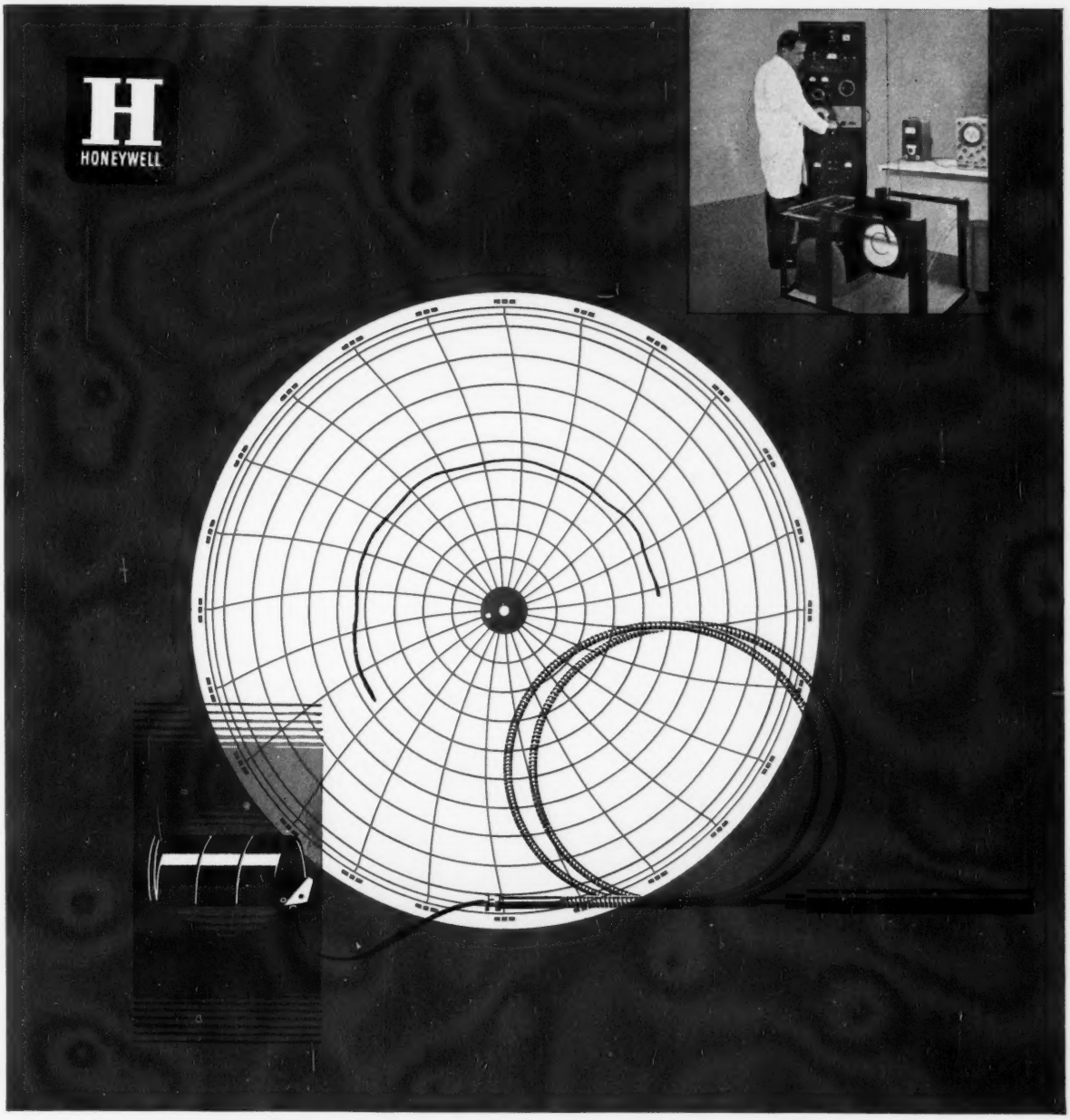
INVITATION FOR ORIGINAL PAPERS

Original papers on Environmental Effects, Simulation, Research, Techniques and Measurements are solicited for the national Technical Meeting and Equipment Exposition of the Institute of Environmental Sciences. Abstracts, clear and explicit, indicative of scope and impact of original developments, should be submitted as 350 to 700 word essays to Frank P. Merry, Technical Program Chairman, 1817 S. Chaparro, Las Cruces, New Mexico.

A brief biography of the author(s) would be appreciated along with the abstract.

Deadlines: Abstracts must be submitted on or before 1 October 1961. Final papers must be submitted on or before 15 January 1962.

1962 Annual Technical Meeting and Equipment Exposition of the Institute of Environmental Sciences will be held at the Sheraton Towers, Chicago, Ill., on April 11 through 13.



The New Honeywell Thermal System withstands extreme vibration and corrosion conditions

Here's a new gas-actuated thermal system that takes the zig-and-zag out of temperature recording under severe vibration conditions.

A complete series of vibration tests has proved the vibration resistance of the new Class III thermal system. In these tests (shown above), the Class III system was installed in a standard Honeywell rectangular case recorder, and subjected to forced vibrations in three mutually perpendicular planes. With accelerations up to 0.2G from 0 to 200 cps, maximum pen oscillation was limited to 1.5%. For more than 75% of the range, pen oscillation was less than 0.5%, with no resonant effects at 60 cycles.

Get the complete story by contacting your nearby Honeywell field engineer. Minneapolis-Honeywell, Wayne and Windrim Aves., Phila. 44, Pa. In Canada, Honeywell Controls, Ltd., Toronto 17, Ont.

Honeywell

H First in Control SINCE 1885

HONEYWELL INTERNATIONAL Sales and Service offices in principal cities of the world. Manufacturing in United States, United Kingdom, Canada, Netherlands, Germany, France, Japan.

NAVAL MEDICAL ENVIRONMENTAL ACTIVITIES

New facilities installed at the Navy Air Crew Equipment Laboratory include a mockup of the Project Mercury Capsule within the large low-pressure chamber and a bioastronautical facility to permit the study of closed ecologic systems. The Project Mercury Capsule mockup will be used for training astronauts. Within the capsule, the astronaut—in a full-pressure suit—will endure programmed, static, space-flight simulation consisting of simulated emergency conditions as evidenced by instruments and actual automatic activation of emergency life-support systems. Programmed simulated flights will require navigation, orientation, timing, and other normal piloting functions of the astronaut, during which simulated emergencies must be met and countered in order to prevent a simulated catastrophe.

The bioastronautical facility is composed of a chamber within a chamber so outboard leakage can be obtained. The versatility of the device was demonstrated by putting six men through an eight-day test. The oxygen was supplied by a solid oxygen source that also acted as a partial carbon-dioxide scrubber. It is recognized that the solid oxygen source plays a major role in removing body odors from the atmosphere—whereas bottled oxygen does not—as well as removing a large percentage of carbon dioxide from the atmosphere.

Two new devices of major importance were installed at the U. S. Navy School of Aviation Medicine, Pensacola, Fla. One of these is the unique Human Disorientation Device, which has since been improved upon by the addition of advanced instrumentation and added computer capacity.

The other new device is the Slow Rotation Room, a 15-foot square room constructed over the hub of the human centrifuge, which will aid in studies of the effects of slow rotation on human subjects for long periods of time.

Three 100,000-foot (altitude) low-pressure chambers were being installed at three air stations: the Marine Corps Air Stations at El Toro, Calif., and Beaufort, S. C., and the Naval Air Station at Cecil Field, Fla.

At the Aviation Medical Acceleration Laboratory in Johnsville, the astronauts were trained on the dynamic flight simulator. This gave them a realistic idea of the acceleration stresses they will encounter during flight. They were also trained with display panels and controls which enabled them to "fly" replicas of their orbital mission. In non-Mercury projects, efforts were made at the Laboratory to develop advanced means of protection against very high g forces, one means being a water-filled "iron-maiden" which permits protection against as much as 31 g's of acceleration force over comparatively long (5-sec.) periods of time.

U. S. Navy Medical News Letter.

INSTITUTE of ENVIRONMENTAL SCIENCES PROCEEDINGS

Year	Member	Non-Member
1959	$8.00	$12.00
1960	$8.00	$12.00
1961	$9.00	$14.00

The above Meeting Proceedings can be obtained from the National Office of the Institute of Environmental Sciences, Postoffice Box 191, Mt. Prospect, Illinois at the indicated rates.

Continued

ENVIRONEWS

administrative controls between the sponsor of a project and the research institute engaged, under contract, to conduct the study. As pointed out in the statement, the sponsor retains basic control over the objective, scope, costs, and timing of research but is relieved of technological administration. Each of these aspects of administrative control is discussed briefly.

Obtainable from Publications Office
Battelle Memorial Institute
505 King Avenue
Columbus 1, Ohio

SERVICES

SHOCK CALIBRATION SERVICE

The new Endevco Corporation Calibration Service is the first and only one to offer shock calibration to 15,000 g's. Inaugurated to advance the state-of-the-art of measuring vibration and shock in environmental testing, this unique Endevco service offers to calibrate any piezoelectric accelerometer weighing less than 2 ounce, regardless of manufacture. If associated electronics in the form of a cathode follower or amplier are included, a system calibration will be furnished.

The Endevco service offers calibration for shock and sinusoidal excitation; calibration throughout a temperature range, high g level calibration; cross-axis sensitivity calibration. For complete infromation and prices address all inquiries to *CUSTOMER SERVICE DEPARTMENT*, Endevco Corporation, 161 East California Boulevard, Pasadena, California or phone SYcamore 5-0271.

CERTIFICATION DISCONTINUED

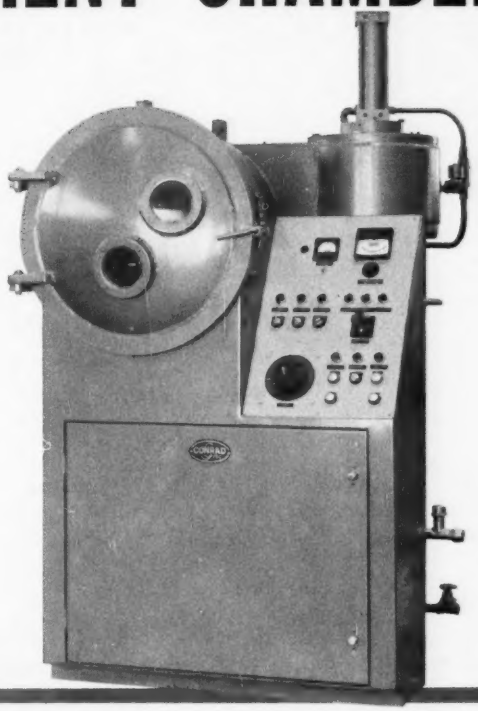
The National Bureau of Standards has discontinued the certification of emf of unsaturated standard cells as of June 30, 1961. An exception will be made for agencies having operations of such a nature as to require these services from the Bureau. The Bureau will continue to undertake calibration of unsaturated cells when special or unusual circumstances are involved.

SPACE ENVIRONMENT CHAMBERS

CONRAD MODEL FH-8

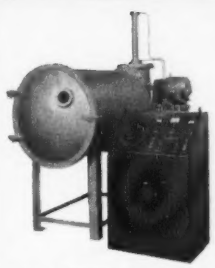
The ideal test chamber for laboratory and small components testing in space research. Chamber 24″ dia., 30″ deep. Requires only 35 sq. ft. of floor area. Integral packaged, complete with vacuum pumping system. Pumping time to 0.5 microns (on a clean, dry empty chamber) 3.5 min. or less. All necessary temperature regulating and indicating instrumentation included. Optional equipment: stainless steel liner, internal light, spare ports.

• Rapid pumping out • Low temperature in minutes • Controlled high temperature • Minimum floor space • Minimum investment

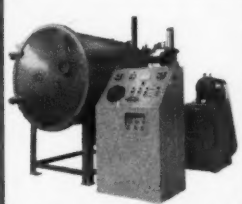


OTHER CONRAD TEST CHAMBERS FOR SPACE RESEARCH

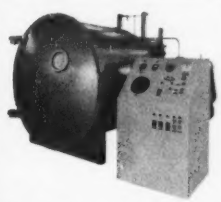
FH-3. Chamber 20″ deep x 18″ diam. Requires only 46″ x 28″ floor area, plus 29″ x 12″ for pump.



FH-35. Chamber 36″ dia. x 60″ deep. Requires only 100 sq. ft. floor area, total.



FH-63. Chamber 48″ dia. x 60″ deep. Requires only 126 sq. ft. floor area, total.



FH-141. Chamber 72″ dia. x 60″ deep. Requires only 210 sq. ft. floor area, total.

DO YOU NEED ALTITUDES TO 500,000 FT. OR MORE?

With floor space at a premium in many laboratories and plants, Conrad's compact Hyper Environment Altitude Chambers offer many advantages for testing small components. They can be supplied for high vacuum into the fractional micron range, with temperature equipment on special order. They require only 35 to 210 sq. ft. of floor area, depending on model of vacuum pumping system. Heating equipment, temperature regulation, and automatic control valve for direct injection of CO_2 or N_2 for rapid cooling are available. Ask your Conrad man for complete specifications, or write the main office.

CONRAD, INC.
CONRAD SQUARE, HOLLAND, MICHIGAN
A subsidiary of Crampton Manufacturing Company

CONRAD Inc.

lance systems. These noises form a "fingerprint" of a ship and are identifiable. They contain frequencies generated by the propeller blades, with the associated cavitation noise of wide bandwidth, vibrations from the engines, gearbox, pumps, motors, generators, fans and other rotating devices. Vibrations are also produced by the crew and by turbulence formed when the laminar flow boundary layer breaks down on the surface of the hull.

The environmental engineer is equipped and trained to use the many instruments needed to record and analyze this noise, inside and outside the hull, and subsequently to propose methods of decoupling, attenuating and sometimes removing the sources. The laboratory then becomes the workshop for evaluating, developing and testing the modifications later to be installed in the ship.

The design engineer is often faced with the problem of selecting the best material or component for a specific application. The lowest priced article can sometimes be the most expensive in the long run, but how is one to be sure? The environmental laboratory is ideally suited to the solution of this problem. By setting up a test program reproducing the most significant environmental conditions for the particular application, the laboratory can test a number of competitive products on a comparative basis at a surprisingly low cost. The confidence level of the results can be made as high as the designer wants and an indication of the reliability and operational limitations of the specimens is an automatic by-product.

Conclusions

The use of an environmental laboratory to improve performance and reliability and reduce costs due to overdesign, built-in failures, and maintenance is an established practice in aeronautical and electronic engineering. The growing use of these facilities in the marine field suggests that the same advantages are available to the naval architect and marine engineer.

The focusing of these activities, previously conducted by a diversified range of engineers as an additional and sometimes tiresome chore, into the Environmental Laboratory has led to refined procedures, new techniques and a growing increase in knowledge. An impetus has been given the development of shock absorbers, vibration decouplers, engine mounts, heat sinks and transfer systems, and the evolution of reliable, high performance components in many fields of engineering.

The environmental laboratory demonstrates the fundamental unity of all engineering disciplines. Heavy government spending to develop missiles and satellites, with their dependence on electronics, has stimulated the evolution of instruments, techniques and men specialized in measuring, reproducing and overcoming natural and man-made environments. These resources are now being applied to many fields of engineering and human activity to the benefit of the designer and the user, and it is apparent that applications exist in the world of ships and marine equipment.

The fierce competition of today, high operating costs and the seemingly permanent threat of war, means that the race goes to the most efficient and most economical. One of the best ways of ensuring that engineering mechanisms and structures are the finest that we can produce lies in the use of the Environmental Laboratory.

MM THE FINEST IN
ENVIRONMENTAL TEST EQUIPMENT

DEPENDABLE operation and accurate tests can only be assured through constant research and the use of highest quality materials and workmanship. Murphy & Miller test equipment is manufactured to the highest standards with quality the prime objective. The true meaning of dependability becomes vital when it is considered that an entire production schedule often hinges upon . . . a dependable test.

MURPHY & MILLER Inc.
ENVIRONMENTAL TEST EQUIPMENT
600 West Taylor Street, Chicago 7, Illinois

ETL
SPECIALISTS IN *LABORATORY* MEASUREMENTS

ELECTRICAL
ELECTRONIC
PHYSICAL
PHOTOMETRIC
CHEMICAL

at

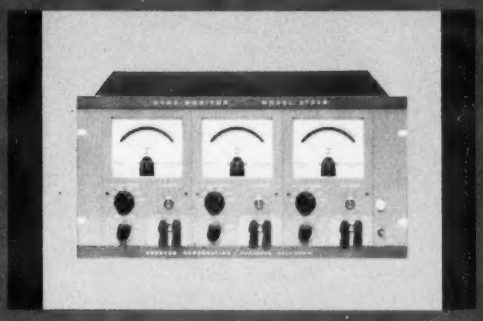
SPECIFIED ENVIRONMENTAL CONDITIONS

Bulletin available on request.

Specializing in:
- Measurements at microwave frequencies
- Calibration of instruments and standards
- Qualification tests per Mil-Specs.

Member—American Council of Independent Laboratories
ELECTRICAL TESTING LABORATORIES, INC.
2 East End Ave., New York 21, N. Y.
BUtterfield 8-2600, Area Code, 212

dynamic instrumentation Σ



Hundreds of Operating Systems
Prove Acceptance...

THE ENDEVCO DYNA-MONITOR

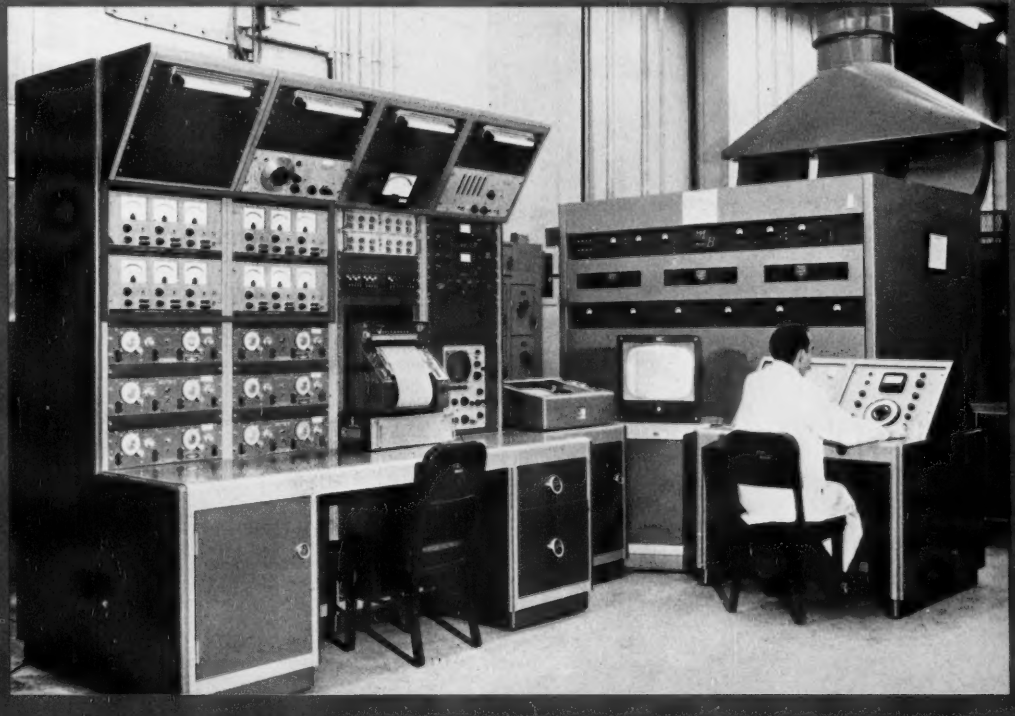
Monitors & Amplifies Vibration, Shock, Pressure & Force Signals

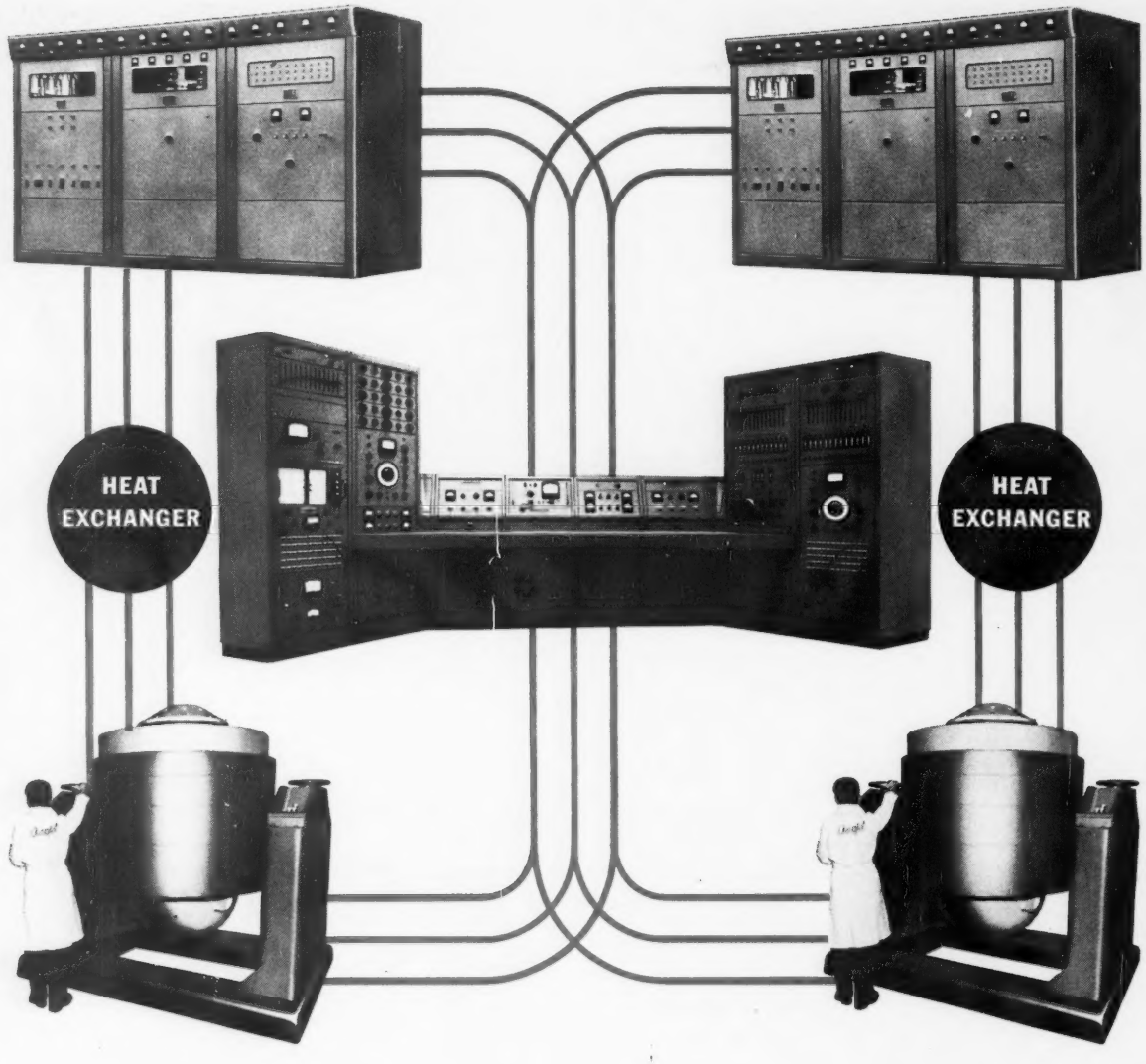
Endevco's Dyna-Monitor shown here in a typical vibration laboratory set-up at General Electric, Light Military Electronic Dept., Johnson City, New York, is a fully integrated laboratory system in one package.

A Driven Guard Shield cable permits remote location of the Dyna-Monitor from a shaker without capacitive signal attenuation. *The Power Amplifier* will drive any high frequency galvanometer directly. *Precision VTVM readout* can also be calibrated in g's by simple procedure. *Large meter* for each of three channels is easy to read and a relay for "shut down" is optional. *Integrated Power Supply* simplifies lash up and saves space. Provision at front for convenient oscilloscope output and filter insertion. *High Gain* provides full scale output of 85 Ma peak or 6 volts rms with only 10 mv peak input signal. Write for descriptive bulletin and prices.

©ENDEVCO CORPORATION 1961 PRINTED IN U.S.A.

ENDEVCO CORPORATION 161 EAST CALIFORNIA BLVD., PASADENA, CALIFORNIA
SYcamore 5-0271 TWX: 7764 CABLE: ENDEVCO





A BETTER SHAKE FOR POLARIS... Aerojet-General installs Ling vibration system with world's highest force rating - 60,000 pounds

When faced with unsolved vibration testing problems on its vital part of the Polaris program, Aerojet-General Corporation, a subsidiary of The General Tire and Rubber Company, turned to Ling Electronics. To give its solid propellant rocket engines the severest shake-up, Aerojet-General improved its test facilities with two Ling vibration systems—controlled simultaneously or independently by one console. The system, now operating, includes two Model 249 shakers delivering 30,000 pounds force each and two Model PP 120/150, 120 KVA water-cooled amplifiers—for a total force delivery of 60,000 pounds. The special random/sine wave console not only provides simultaneous or independent control of both exciter systems, but features Ling's famous ESD-ASD 20 spectral density equalizer/analyzer, the industry standard. Like Aerojet-General, you too may find the superior quality and rugged reliability of Ling systems answer your testing problems. For more information, write Department JES-861 at the address below.

LING-TEMCO ELECTRONICS, INC.

LING ELECTRONICS DIVISION

1515 SOUTH MANCHESTER, ANAHEIM, CALIFORNIA • PRospect 4-2900